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ABSTRACT

Communication is defined and the neurological bases of it and its disorders are discussed. The prevalence and costs of communicative disorders are described; current research and financial support for it and for training of investigators are reviewed. Details are then given concerning research on hearing, including the auditory system and its functions, the pathology of the auditory system in relation to hearing, and educational and rehabilitative management of auditory disorders. Research on central processes is also presented, covering characteristics of the central segment in the communicative process, the nature and scope of central processes, and gap areas in language disorders. Last, research on speech production is surveyed in the areas of normal speech production systems and processes, pathologies affecting the system, speech disorders without known organic pathology, management and treatment, and training needs. (JD)

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HUMAN COMMUNICATION AND ITS DISORDERS— AN OVERVIEW

A Report
Prepared and published by the
Subcommittee on Human Communication and Its Disorders

NATIONAL ADVISORY NEUROLOGICAL DISEASES AND
STROKE COUNCIL

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1969

Preface

On October 20, 1964, Dr. Richard L. Masland, Director, National Institute of Neurological Diseases and Blindness, met with representatives of the Institute's Communicative Disorders Research Training Committee, of the Communicative Sciences Study Section, Division of Research Grants, NIH, and of the NIH staff associated with these two groups. The purpose was to discuss the need for a detailed analysis of the contemporary status of research in the communicative sciences and the need for future program development in this area. The outcome of the October 20 meeting was the establishment of a pro tem Human Communication Task Force. This Task Force held two meetings to survey the problems involved and to give general advice.

In consequence of the Task Force's work, the National Advisory Neurological Diseases and Blindness Council (NANDB) established a Subcommittee on Human Communication and Its Disorders in March, 1965. This new group was originally under the chairmanship of Dr. Francis A. Sooy. The Subcommittee held its first meeting that same month in Chicago. In preparation for that meeting Dr. Eldon L. Eagles, Assistant Director, National Institute of Neurological Diseases and Blindness, expressed the charge to the Subcommittee as follows:

> In order to provide bases for proper program planning, the National Institute of Neurological Diseases and Blindness has a continuing need to review the impact of the various programs on research and training in communicative sciences and communicative disorders. It is also important that the scientific community realize the effect of these programs. Furthermore, the Institute has the responsibility to keep the people and the Congress informed. The need to review and assess programs has become more acute as these programs have grown; for example, in the past nine years the Institute's expenditures for research and training in human communication increased tenfold. One method of gathering information to accomplish these aims is to ask a representative group of individuals from the scientific community to review the status of research and training with respect to a particular field. With this approach in mind, the NANDB Council has established the Subcommittee on Human Communication and Its Disorders. The NANDB Council has suggested the following as the Subcommittee's objectives:
>
> 1. To define the extent of the field of human communication and its disorders,
> 2. To review the present status of research in human communication and its disorders,
> 3. To outline unresolved problems and unmet needs with recommendations as to their solution.

The Subcommittee's first activity, in response to its charge, was to undertake the definition of the extent of the field of human communication and its disorders. It quickly became apparent that very sharp restrictions in this definition would need to be made. Human communication is so multifaceted that many of its aspects are far removed from the sphere of the Institute. It was therefore agreed that, for purposes of the analysis, the Subcommittee would restrict its attention primarily to verbal symbolic exchange in terms of the individual, both as a sender and as a receiver.

Within this frame of reference, the Subcommittee (aided by more than a hundred persons with special knowledge) has undertaken a three-fold task. One phase has been to survey the research activities, the programs of personnel training and the scope of contemporary management of human communicative problems, with major but not exclusive emphasis upon the areas of responsibility of the National Institutes of Health in general and the (now) National Institute of Neurological Diseases and Stroke in particular. The second phase has been to define both 1) needs for research on human communication and its disorders and 2) needs for personnel to perform such research and to teach others to do so. The last phase of the Subcommittee's work has been to prepare recommendations for the NANDS Council as to the steps which NINDS could take so as to discharge with greater effectiveness its responsibility in the areas of communicative science and of communicative disorders.

The report which follows presents in slightly modified form the portions of the Subcommittee's report which deal with the first two of the aforementioned phases of its work. Of course, no member of the Subcommittee nor any other member of the professional community which the Subcommittee represents can be fully happy with its report, since no overview can do justice to a field so complex. However, the Subcommittee hopes that its remarks will prove useful to those who consult them.

This report represents the composite endeavors of many dedicated individuals.

Notable has been the work performed by the members of the Subcommittee itself, whose labors produced this manuscript. All were involved throughout the process of planning, of writing and of editing, but the following special credits should be noted. Dr. Gerard J. Canter prepared sections of Chapter 1. Dr. Ernest G. Wever, Dr. Francis A. Sooy and I developed Chapter 3. Dr. William G. Hardy assembled Chapter 4. Dr. Stanley H. Ainsworth, Dr. James E. Curtis and Dr. Joseph H. Ogura wrote Chapter 5. The major portion of the actual writing of the remainder of the report fell to my lot.

The Human Communication Task Force which laid the foundation for the establishment of the Subcommittee consisted of Dr. Francis I. Catlin, Dr. David D. DeWeese and Dr. Henry B. Perlman, plus Dr. Frances A. Sooy and myself. Dr. John A. Kirchner participated in the initial meeting of the Subcommittee (March 1965), and Dr. Bruce W. Konigsmark served as a resource person in several subsequent meetings.

Particular thanks are due to Dr. Richard M. Flower for assistance in writing Chapter 3 and to Dr. William Marowitz for help in writing Chapter 5.

The Subcommittee received help from many persons in the form of resumes of problem areas, summaries of the status of divisions within the field, reactions to materials generated by the Subcommittee and special statistical compilations. The Subcommittee gratefully thanks all who thus assisted it. Among these individuals were Dr. Franz Altmann, Dr. Bernard M. Anderman (Veterans Administration), Dr. Godfrey E. Arnold, Dr. Barry J. Anson, Dr. Moe Bergman, Dr. Lawrence R. Boies, Dr. James F. Bosma, Dr. Arend Bouhuys, Dr. Joe R. Brown, Rev. Thomas J. Carroll, Dr. Robert B. Chaney, Dr. W. E. Compere, Jr., Dr. Walter P. Covell, Dr. David E. Crowley, Dr. Peter J. Dallos, Dr. Frederick L. Darley, Dr. Rita B. Eisenberg, Dr. Hans Engstrom, Dr. D. Robert Frisina, Dr. J. Roswell Gallagher, Dr. Aram Glorig, Dr. Jay M. Goldberg, Dr. Robert Goldstein, Dr. Victor Goodhill, Dr. Frederick R. Guilford, Dr. Miriam Pauls Hardy, Dr. Earl R. Harford, Dr. J. Donald Harris, Dr. Joseph E. Hawkins, Jr., Dr. O. W. Henson, Jr., Dr. Ira J. Hirsh, Dr. Lloyd A. Jeffress, Dr. James Jerger, Dr. George Kelemen, Dr. Nelson Y-S Kiang, Dr. Fernando R. Kirchner, Dr. Masukazu Konishi, Dr. Merle Lawrence, Miss Frances S. Lichtenberg (American Speech and Hearing

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The Subcommittee thanks the *American Annals of the Deaf*, Dr. D. Robert Frisina and the *Journal of Speech and Hearing Disorders* for permission to reproduce certain textual material appearing in Chapter 2. The Subcommittee is also grateful to The Orton Society, Dr. Richard L. Masland, Easter Seal Society for Crippled Children and Adults of California, Dr. William G. Hardy, the C. V. Mosby Co., Dr. Douglas Buchanan, Dr. Arthur H. Keeney and Dr. Virginia T. Keeney for permission to reproduce materials appearing in Chapter 4. The Subcommittee thanks Bell Telephone Laboratories, Dr. Peter Denes and Dr. Elliot Pinson for permission to reproduce Figure 1 in Chapter 5.

Mrs. Laura Reiter and her assistants typed preliminary drafts of several chapters, and she otherwise maintained the secretarial continuity of the project after I assumed chairmanship of the Subcommittee.

Finally, my wife, Mary Ellen Carhart, was not only a continuing inspiration to my work for the Subcommittee but also helped greatly in the analysis and tabulation of its summaries presented in Chapter 2.

RAYMOND CARHART, PH.D.
Chairman
Subcommittee on Human Communication and Its Disorders

SUBCOMMITTEE ON
HUMAN COMMUNICATION AND ITS DISORDERS
# of the
NATIONAL ADVISORY NEUROLOGICAL DISEASES AND STROKE COUNCIL

RAYMOND CARHART, PH.D. (1965-68)
(*Chairman:* 1967-68)
Professor of Audiology
Northwestern University
Evanston, Illinois

WILLIAM S. HARDY, PH.D. (1965-68)
(*Executive Secretary*)
Professor and Director
Hearing and Speech Center
Johns Hopkins Hospital
Baltimore, Maryland

STANLEY H. AINSWORTH, PH.D. (1965-68)
Professor and Chairman
Program for Exceptional Children
University of Georgia
Athens, Georgia

DOUGLAS N. BUCHANAN, M.D. (1966-68)
Professor Emeritus
Department of Pediatrics
University of Chicago
Chicago, Illinois

JAMES E. CURTIS, PH.D. (1965-68)
Professor
Speech Pathology and Audiology
State University of Iowa
Iowa City, Iowa

JON EISENSON, PH.D. (1965-68)
Professor
Speech Pathology and Audiology
School of Medicine
Stanford University
Palo Alto, California

FRANCIS A. SOOY, M.D. (1965-68)
(*Chairman:* 1965-66)
Professor and Chairman
Division of Otolaryngology
San Francisco Medical Center
University of California
San Francisco, California

PAUL MUSSEN, PH.D. (1965-67)
Professor of Psychology
University of California
Berkeley, California

JOSEPH H. OGURA, M.D. (1965-68)
Professor and Head
Department of Otolaryngology
School of Medicine
Washington University
St. Louis, Missouri

ERNEST G. WEVER, PH.D. (1965-68)
Professor of Psychology
Princeton University
Princeton, New Jersey

GERALD J. CANTER, PH.D. (1966-68)
(*Editorial Integrator*)
Associate Professor of Speech Pathology
Northwestern University
Evanston, Illinois

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Chapter 1—DEFINITION OF HUMAN COMMUNICATION AND ITS DISORDERS

I. THE GENERAL SCOPE OF COMMUNICATION

Communication, which is the transmitting and exchanging of information, exists in many forms and occurs for many purposes. It is a primary ingredient in the biological world, the cohesive force in every human culture and the dominant influence in the personal life of every one of us.

Such being the case, many fields of knowledge, many disciplines and many professions lay claim, with justice, to some facet of its *corpus*. Thus, in defining human communication and its disorders as an area of proper attention for the National Institute of Neurological Diseases and Stroke, the first task was to review quickly the diversity of communicational processes and levels. The responsibility of the Institute rapidly becomes clear against such an overview.

A. *Machine Communication*—Some professions deal with communicational processes that occur in the physical world and that do not require participation of human beings. To be sure, men benefit from the accomplishments of these areas; but men are the consumers rather than the objects of their endeavors. The electrical engineer, for example, transmits signals (in the forms of waves and pulses) from one place to another. He manipulates these signals within electronic instruments. We find these signals useful in many ways; but the engineer's frame of reference includes the premise that one machine, once properly constructed, can exchange information with a second machine in the absence of any human intermediary.

B. *Biological Communication*—Other professions deal with communicational processes that are strictly biological.

One such form of communication is found in the genetic code that is encapsulated in the molecular chains forming the microstructure of genes. The biochemist who concentrates on this problem aims to define the molecular entities and sub-entities whereby one generation transmits to the next all the complexities of its structures and its basic functions. Here the phenomena are eon-spanning communicative processes that pervade all life, yet they have high specificity for each species and even for each individual within the species.

Another form of biological communication is found in the codes and clues which are employed throughout much of the animal world to achieve survival of the individual and/or survival of the species. The ornithologist who studies the significances of bird sounds, be they mating songs, declarations of territorial right, or calls to migration, is concerned with such communication. So is the entomologist who investigates the role of the chemical sense in bringing butterflies together for mating. The distinctive feature of these phenomena is that these signals and the responses to them, though transient, are predominantly instinctive. They do not possess the potential for modification and for elaboration that characterizes Man's use of communication.

C. *Mass Communication*—At what might be classed the opposite end of the scale, other professions are concerned with communication as a socio-political force. These professions encompass the disciplines that employ mass communication. Journalism uses the printed word to report local, national and international happenings to all who will heed, while radio and television do likewise via newscasts and feature programs. The broadcasting and motion picture industries, along with the live theatre, the concert stage and allied outlets for artistic expression, entertain the public and satisfy its aesthetic appetites. Politics uses some of these same media, as well as the public platform, for the very different purpose of influencing voters and controlling attitudes. Analogously, the advertising and public relations businesses seek to mold images and determine buying habits. And possibly the epitome of the use of mass communication for socio-political purposes appears in those nations where only the Propaganda Ministry is heard and where ideologies are thereby kept circumscribed.

D. *Social Communication*—Viewed as the vehicle for more intimate social interaction, communication among groups and among individuals supplies the sinews that make possible industry, commerce, international relations and the structure of our culture. Face-to-face conversations, letters, telephone calls, committee meetings and conventions; memoranda, invoices and bills of lading; laws, ordinances and codes of conduct; legislative proceedings, diplomatic exchanges and court hearings; the organizations, professional associations, labor unions, political parties and religious faiths are but a few of the many channels whereby Society achieves its cohesion, preserves its components, and modifies its form.

It is the social sciences which deal with the phenomena generated by communication at these various levels. The interactions are complex, producing a multitude of cultural and economic relationships and entities. Thus, for example, the effects of communicational interplay are as apparent in the mores of an aboriginal tribe as in the mores of the "hippics" or of the Bible belt. And since such interplay is determining the future of all our institutions, from the family to the United Nations, the social sciences are inevitably communication-oriented disciplines.

E. *Utilization of Knowledge*—Somewhat analogously, communication is essential to the creation of knowledge, to its preservation and to its transmission to succeeding generations. New concepts must be codified in forms that allow other persons to understand them. Only then can these concepts be refined through the criticisms and reactions they receive. Only then can these concepts, including many forms of artistic accomplishment, be preserved in books and in other publications, on films and by recordings. Our libraries are storehouses of materials from the past awaiting transmittal to future recipients. Our classrooms are the formal portals through which young people are readied to utilize these archives. Man has been called the "time-binding" creature because he can use his communicational skills to encapsulate his experiences and then to convey, even across centuries, the wisdom he has gained from these experiences.

F. *Systems of Representation*—Communication requires the use of codes, symbol systems and languages. Humanity has developed many such methods. and they are, of course, the objects of much study. For example, the lexicographer creates dictionaries by cataloguing word and symbol usage; while the grammarian concerns himself with analyzing the general principles and particular rules for speaking or writing a language. The problem of how meaning is originally inserted into symbol systems is more subtle. Somehow we human beings have the capacity to acquire use of many languages to convey our feelings, observations, ideas and intentions. The question as to why and how this is possible lies in the realm of linguistics, which is a subject that copes with topics as varied as that of determining what universals in symbol manipulation undergird all languages to that of analyzing the phonemic, semantic and syntactic features of particular languages.

G. *Communication as a Personal Activity*—In the final analysis, of course, human communication must also be considered from the standpoint of the individual.

All normal persons, and most who are not normal, learn those portions of the language (or languages) of their culture that are essential to the everyday exchange of ideas. Each then employs these skills as his major means of social adjustment. He thus functions amid the complex of social institutions that surround him, conforming to the mores of his culture and reaching such achievements as becoming gainfully employed. It is through the language he has learned that mass communication media can thus affect him. But probably most importantly, each individual uses the language he has acquired to carry on his daily private and highly personal interactions with those few other individuals who are his intimates. Through these people and their communication with him, he satisfies the deep subjective needs which are his heritage as a gregarious creature. His close companions during infancy and childhood teach him his first lessons in human living. They help him mature to the point where he can enter wider society. Thereafter a changing group of intimates gives him emotional sustenance throughout the stages of his life. Truly, the man or woman without either friends or family is a sad and withering anomaly.

Naturally, communication as a function of the normal individual and as a phenomenon in his moment-to-moment adjustments receives strong attention. Wide is the gamut of scientific questions covered. These extend, to take a few examples, from analysis of the stages whereby a tiny child acquires his Mother Tongue to psychiatric evaluation of the subtle non-verbal signals which we each exude; or from the description of how the nervous system processes incoming speech to identification of the muscular actions that produce the reply; or from determination of the parameters that control speech intelligibility in a noisy listening environment to analysis of how the social climate of the moment affects a person's interpretation of what he hears. And on, and on and on.

Naturally, too, much inquiry deals with aberrations in the individual's communicative capacity. Disorders of this capacity may arise from many causes and at any stage in life. Their common feature is that they handicap personal adjustment and impair social efficiency. For example, damage to the auditory system can interfere with hearing for speech. When this damage occurs early enough, a child will neither acquire language normally nor learn to talk normally. Even when it comes later, a hearing impairment throws a haze over a listener's effort to understand others. Likewise, damage in the central nervous system can impede the understanding of speech even though this speech is being received satisfactorily by the ear. Early in life such a central disorder can cause major perceptual and learning problems, while in the later years it can disrupt the entire structure of learned communicative adjustment. Finally, there may be damage to or malfunction of the speech producing mechanism. The resulting speech disorders include diverse problems, such as the bizarre articulation of the child born with cleft palate or the laborings of the stutterer.

H. *Summary*—Communication in its broadest sense is a kaleidoscope of processes operating in numerous ways, existing at various levels and having many kinds of effect. Human communication stands as the major subdivision within this framework. It, too, has many facets and ramifications. It is simultaneously 1) the mechanism for influencing the masses, 2) the foundation for social organization, 3) the vehicle for our intellectual heritage and 4) the medium whereby each individual adjusts to his fellow men. Obviously, the scope of human communication extends beyond the boundaries of any single discipline, profession or segment of our society. However, there are substantial sections of this complex of phenomena that fall clearly within the province of the National Institute of Neurological Diseases and Stroke. Hence, with the foregoing overview in mind, we now turn to the task of designating those facets of human communication and its disorders for which the Institute should feel a primary responsibility.

II. RELATION TO THE MISSION OF NINDS

The National Institute of Neurological Diseases and Blindness (recently renamed the National Institute of Neurological Diseases and Stroke) was established in August, 1950 by Public Law 692—81st Congress. This act states:

> "The Surgeon General shall establish in the Public Health Service . . . an institute for research on neurological diseases (including epilepsy, cerebral palsy, and multiple sclerosis) and blindness, and he shall also establish a national advisory council . . . to advise, consult with, and make recommendations to him with respect to the activities of the institute. . . .
>
> ". . . the purpose of this Act is to improve the health of the people of the United States through the conduct of researches, investigations, experiments, and demonstrations relating to the cause, prevention, and methods of diagnosis and treatment of . . . multiple sclerosis, cerebral palsy, epilepsy, poliomyelitis, blindness . . . and other diseases; assist and foster such researches and other activities by public and private agencies, and promote the coordination of all such researches and activities and the useful application of their results; provide training in matters relating to such diseases; and develop, and assist States and other agencies in the use of the most effective methods of prevention, diagnosis and treatment of such diseases."

The mission of the Institute of Neurological Diseases and Stroke, as specified by the charge just quoted, clearly implies the *Institute's responsibility to devote major attention to those processes of human communication which are carried on by and within the individual.*

The reason for this responsibility is immediately apparent when we remember that ALL THE COMMUNICATIVE ACTIVITIES WHICH A PERSON UNDERTAKES ARE THE PRODUCT OF HIS NERVOUS SYSTEM. Whether one is concerned with an individual's effectiveness in private life or his competence in broader social contexts, it is a primary fact that a person cannot develop and maintain satisfactory communicational capacities unless his nervous system, with its associated sense organs and muscles, is normal. The second primary fact is that many kinds of developmental deficit, disease, injury, and malfunction of this system bring about disturbances of these capacities. These disturbances cause communicative disorders that, in the child, disrupt personal maturation and delay social development and, in the adult, interfere with full, well-adjusted and productive living.

Stated conversely, there are facets of human communication which constitute strictly sociological and group phenomena. These fall beyond the responsibility of the National Institute of Neurological Diseases and Stroke. However, any circumstances that react upon the individual so as to affect adversely the neurological and muscular process of his own communicative behavior are within the mission of the Institute. It follows, furthermore, that the Institute has a direct interest in all facets of the normal communicative processes occurring within the individual which may in any way help in understanding breakdown in these processes. It is true that in the final analysis the mission of the Institute in this area is 1) to discover and to improve procedures for diagnosis, treatment, therapy and management of communicative disorders and 2) to train research personnel in these areas. But this mission can proceed as it should only by increasing our knowledge of the nature and the sub-structure of normal communication to the point where communicative disorders can be fully evaluated by contrast.

In view of these considerations it is appropriate for this report next to review the neurological scope of normal human communication and then to summarize the neurological foundations for disordered communication.

III. NEUROLOGICAL FOUNDATIONS OF NORMAL COMMUNICATION

Figure 1-1 presents a schematic diagram of the portions of the nervous system that are most critical to communicative behavior. This representation has been simplified to the extreme, but it serves in a very general way to point out the three main divisions of the system and the variety of activities each performs.

The first major division of the neural system participating in communicative activity is the receptor segment. Meaningful stimuli in the form of patterns of sound, light, or mechanical disturbances activate the appropriate sensory complexes (auditory, visual or tactile mechanism). Each sensory complex encodes incoming stimulation into patterns of neural impulses which, after recoding and processing enroute, reach the appropriate primary sensory area of the cerebral hemispheres. The end result is the delivery of patterned neural impulses which are transformed into a symbolic and linguistic stream within the central processor. This central processor is shown in the diagram very simply because its complexity defies any reasonable schematic representation on a single sheet of paper. Moreover, we still know practically nothing about what events occur here or how they proceed. However, we can say that in consequence of these events each incoming neural message is structured into a symbolic and linguistic entity. It acquires meaning and becomes the focus of consciousness. We can also say that these events often trigger reactions which culminate in a reply.

Such a reply is produced physically by the third, or effector, segment of the system. This segment is also the channel for expression of thoughts which are generated without immediate prior stimulation from another person. In either event, complex neural reactions with major focus in the motor areas of the cortex produce response in either the speech mechanism, the writing mechanism and/or one of the sundry less-formalized mechanisms (such as gesturing). In the case of the speech mechanism, for example, the muscles of the face, tongue, throat, larynx and torso are activated in adroitly coordinated sequences. The end result is a breath stream which generates trains of sound from within the larynx and articulatory tract. These sounds are the intricately patterned stimuli which, when heard by another person, can initiate analogous sequences of communicative behavior (receptor, central and effector processes) within the second person's nervous system.

Clearly, the foregoing description is the briefest of thumb-nail sketches. Some further insight into the intricacies that exist can be gleaned from special conferences sponsored by NINDS such as reported in *Brain Mechanisms Underlying Speech and Language* (Ed. Clark H. Millikan and Frederic L. Darley, New York: Grune and Stratton, 1967) or *Speech, Language, and Communication* (Ed. Edward C. Cartarette, Berkeley: University of California Press, 1966).

Within the framework of the very simple discussion being given here, there are four additional features requiring mention.

The first one is obvious: namely, that the nervous system actually is so unified and interconnected that any division into segments, such as we have made for this discussion, is an artificial one whose value lies in the convenience with which it allows us to organize our thinking.

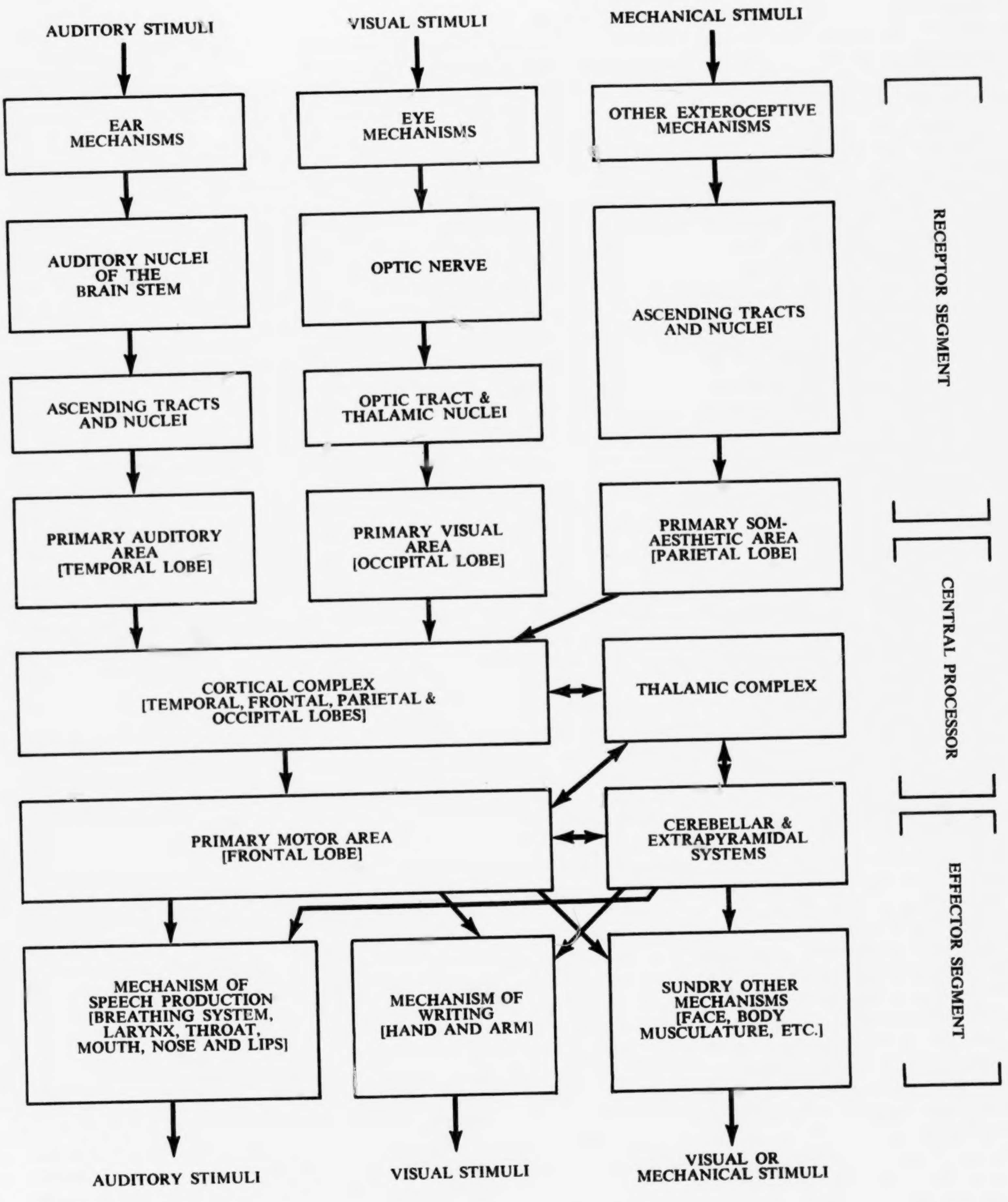
The second feature illustrates the first one. All stages of neural activity comprising communicative behavior are permeated by feedback. Successive communicative functions occur as smoothly as they do because of the intricate two-way connections among neural levels. Thus, for example, a talker proceeds smoothly within his own speech (effector function) because he hears himself (receptor function) and monitors his utterance for acceptability (central processor function).

Third, and still in the same vein, sub-cortical centers and pathways are involved much more in the central and effector functions than our description has implied. Figure 1 gives the barest indication of this fact by showing the thalamic complex, the cerebellum and the extrapyramidal systems; but no attempt is made in the figure to hint at the labyrinth of sub-cortical interconnections that are important.

Finally, it is critical to remember that the functions of the central processor encompass events of discrimination and memory that are due to the long train of earlier events in a person's life and to his copious communicational stimulation in the past. The behaviors of today can occur only because of the reactions incited throughout many yesterdays; and so evaluation of the communicative process requires not only analysis of what is happening at the moment but also recognition of the role played by prior experience.

IV. NEUROLOGICAL FOUNDATIONS OF DISORDERED COMMUNICATION

At this point we must stress again the fact that viewed neurologically, the communicative process is a unitary one. The entire sequence of sensori-neuro-muscular events must occur properly for human communication to occur normally. Consequently, a developmental malformation, an injury, a disease, a functional derangement, an extirpation or a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EYE MECHANISMS
OTHER EXTEROCEPTIVE MECHANISMS
AUDITORY NUCLEI OF THE BRAIN STEM
OPTIC NERVE
ASCENDING TRACTS AND NUCLEI
ASCENDING TRACTS AND NUCLEI
OPTIC TRACT & THALAMIC NUCLEI
PRIMARY AUDITORY AREA [TEMPORAL LOBE]
PRIMARY VISUAL AREA [OCCIPITAL LOBE]
PRIMARY SOMAESTHETIC AREA [PARIETAL LOBE]
CORTICAL COMPLEX [TEMPORAL, FRONTAL, PARIETAL & OCCIPITAL LOBES]
THALAMIC COMPLEX
PRIMARY MOTOR AREA [FRONTAL LOBE]
CEREBELLAR & EXTRAPYRAMIDAL SYSTEMS
MECHANISM OF SPEECH PRODUCTION [BREATHING SYSTEM, LARYNX, THROAT, MOUTH, NOSE AND LIPS]
MECHANISM OF WRITING [HAND AND ARM]
SUNDRY OTHER MECHANISMS [FACE, BODY MUSCULATURE, ETC.]
AUDITORY STIMULI
VISUAL STIMULI
VISUAL OR MECHANICAL STIMULI
RECEPTOR SEGMENT
CENTRAL PROCESSOR
EFFECTOR SEGMENT

Figure 1-1. Schematic diagram of neural mechanisms for human communication.

degeneration which disturbs this sequence may produce a communicative disorder in the individual suffering it. Also, since different processes take place at successive stages in the normal communicational sequence, the site and extent of the abnormality will determine the nature, severity and permanence of the disorder that results.

Because of this last fact, communicative disorders are often divided into three categories. These divisions parallel the three segments of the normal communicative process that are described earlier. The NANDS Subcommittee on Human Communication and Its Disorders has employed these same divisions in organizing and preparing the present report. These categories are 1) disorders of the receptor segment, or input system, 2) disorders of the central processor, or symbol-handling mechanism, and 3) disorders of the effector segment, or output system. To be sure, such a classification is imperfect, and there are disorders which properly belong under at least two headings. On the whole, however, this scheme allows for a definitive analysis of the kinds of problems that must be met in dealing with disorders of human communication within the individual. Hence the Subcommittee has organized its discussions according to this tripartite pattern, and a brief description of the communicative problems encompassed within each subdivision is appropriate next.

A. *Disorders of Reception.* The portions of this report which deal with disorders of the input system will cover only problems of hearing, even though the receptor segment can also function through the visual and the tactile sensory modalities. The reasons for this restriction are simple. In 1967 the NANDB Council received a report on Vision and Its Disorders (NINDB Monograph No. 4, Public Health Service Publication No. 1688) from the Subcommittee appointed by the Council to review research needs in the field of vision. This analysis is thorough. It needs no supplementation by us. The tactile modality, although importantly involved in feedback control during speech production, conventionally serves only as a crude communicative medium in its own right. Thus, it is in the realm of hearing, i.e., in the reception of the spoken language, that we find those major disorders of the receptor segment still awaiting review for the NANDS Council.

The input system, when one considers spoken language, consists of the ear and its associated central auditory tracts up to the cerebral cortex (see Figure 1-1). The receptor processes which take place within this sytem are primarily those of signal transmission and pre-linguistic neural coding. In consequence, the damages and malfunctions that occur in this system produce two types of problems: loss in auditory sensitivity and dysacusis. Loss in sensitivity is characterized by unresponsiveness to sounds that would normally be heard, while dysacusis is characterized by garbling of stimuli which are strong enough to be audible.

One example of loss in sensitivity is furnished by the child born with closed ear canals (congenital atresia). Sound can not enter this child's inner ears at normal intensity, with the consequence that many of the weaker sounds others would hear do not reach the youngster's threshold for neural response. A child with this type of deformity has a communicative disorder because much of the ordinary conversation in his environment is spoken at too faint a level to penetrate the abnormal mechanical barrier in his ear canals.

Among other examples of loss in sensitivity are adults who suffer either stapedial fixation or cochlear damage from otosclerosis, children with congenital and hereditary deafness, victims of noise-induced hearing loss and elderly persons with some forms of presbycusis. The problems in communication which such individuals face are those arising from the fact that the speech of their environment is too faint for them, so that they either are deprived of hearing speech at all or of hearing it intact. Most persons who have learned language before acquiring such a hearing loss are relatively fortunate. Their primary need is to have auditory stimulation restored. Such restoration is usually possible either through surgery, medical therapy or sound amplification (hearing aids). When such restoration is not possible, which is rare, the victim must develop substitute input skills (i.e., lip reading). By contrast, when the hearing handicap appears early in life and is severe enough, the infant and young child does not receive enough speech stimulation so that he can learn language normally. That is, he fails to acquire the fundamental ingredients of human communication as he should merely because his sensory deficit has kept him from being exposed adequately to his Mother Tongue. Such a child will not achieve immediate improvement in communicative competency merely by having his hearing loss eliminated surgically or by supplying him with amplified sound. Meticulous and prolonged training, utilizing the special pedagogical skills that have been developed for this purpose, must be completed before such a child can learn the communicative competence which an adult with a similar amount of impairment recaptures quickly once his problem is properly managed.

Dysacusis occurs when the patterns of afferent neural signals are disrupted so that incoming speech stimuli lose some of their intelligibility although the afferent signals are still of adequate strength. To be sure, dysacusis frequently occurs in combination with reduced auditory sensitivity, but it need not be thus. A good example of a combination of both deficits is offered by Meniere's disease. This disease is characterized by abnormal secretion of fluid (endolymph) within the inner ear. More intense sounds than normal are needed before stimulation first occurs; but even after this deficit in acuity has been overcome by increasing the sound intensity, a dysacusic fuzziness persists in what is now a strongly perceived stimulus. During acute stages of the disease both problems can become aggravated.

Among other causes of dysacusis are tumors of the auditory nerve, auditory damage due to some drugs (i.e., dihydrostreptomycin), some hereditary conditions and damage within the central afferent system. This latter type of damage is relatively rare and also relatively subtle. Its symptomatology usually is dysacusis without any associated impairment of sensitivity, but it has special importance because it may be a symptom of central pathology, such as a tumor, that may eventually threaten life.

As regards management, the condition causing dysacusis can sometimes be removed by appropriate medication. At other times dysacusis is a symptom of a condition requiring neurosurgery. Such surgery may necessitate damaging the auditory nerve and thus increasing the hearing problem. Dysacusis is a relatively unchanging disorder in the remaining cases. Unfortunately, hearing aids offer little help to dysacusis because such instruments can not counteract the garbling of the signal that occurs within the nervous system. True, hearing aids still have some place, but other educational and habilitational procedures now assume greater importance. And, of course, it is critical to stress that when dysacusis occurs early in life, it adds greatly to the burden of handicap because dysacusis interferes with the learning of speech and language by garbling stimuli that are strong enough otherwise to be clearly heard.

B. *Disorders of Central Processing*—We recall that the middle section of the neural system that is involved in communication activities consists of the cortical (and sub-cortical) complex that lies between the receptor and effector segments (Figure 1-1). The functions that are carried out here result in conscious perception, assignment of meaning and establishment of relation. Linguistic competencies are mediated at this level. Hence, damages and malfunctions which occur within this central processor inhibit or disrupt language function, symbol usage and message interpretation.

There are two useful ways in which one may classify the various communicative disorders resulting from damages and malfunctions within the central processor. One method is to distinguish between the problems of childhood and those of adulthood. The second is to separate symptomatologies on the basis of whether the communicative disorder is primarily (1) one of interpreting incoming messages, (2) one of manipulating symbolic and conceptual relations, or (3) one of generating meaningful expressive language. Each approach has distinctive merits, so we shall review each very briefly.

The disorders of central communicational processes found in early childhood are usually due to disease or injury. Damage may occur prenatally (i.e., sometimes due to rubella early in the gestation period), at or immediately after birth (i.e., sometimes occurring from obstetrical injury or from kernicterus), or thereafter (i.e., sometimes following head injury). As one would expect, the outstanding feature of such cases is interference with the acquisition of linguistic skills and of proficiencies in symbol manipulation. Perceptual difficulties and learning disabilities outside the linguistic realm may also be present and may complicate adjustment. Unless the damage has produced general biologic retardation, in which case all language development is slowed down, some central capacities may be relatively unaffected and some facets of language acquisition are likely to be less disrupted than others. The point to be stressed is that although multiple disorders are common, most children with such problems have good potential in many directions. However, they find their educational and social progress disproportionately hindered because they have not been able to learn some of the language skills normal for their ages. Such being the case, and since neither medication nor surgery will ordinarily eliminate the underlying neurological deficit, special training and special educational programs are the most promising methods for managing these children. Moreover, of course, a primary goal for the future must be to reduce the instances in which the central nervous system is damaged in the first place.

The obvious disorders of the central communicational processes that appear in later life are usually the product of brain damage from neurosurgery, from accidental head injury or from a cerebrovascular episode. Here the outstanding symptoms are the loss of linguistic capacities that were previously well established. These disorders range from global disturbances which disupt the entire communicative act to impairment only of relatively specific skills, such as the ability to read written language. These disorders are, of course, of secondary importance as long as the patient's life is in danger or he is in an acute stage of illness. They acquire primary significance when they persist as long-term residues during the recuperative and post-recuperative periods. When such is the case, proper patient management requires training regimes designed to re-establish the lost linguistic capacities.

More subtle disorders of the central communicational capacities frequently appear among adults in connection with the gradual neurological degeneration of later years. These disorders are sufficiently undramatic so that they have often gone unnoticed, usually being considered as aspects of general intellectual deterioration. This latter view disregards the fact that some linguistic functions are susceptible to disruption before general intellectual capacity fades. The linguistic functions which are involved here are those of interpreting incoming speech. Many older people have trouble understanding what is said to them rapidly or in situations that are acoustically distracting. However, they understand immediately when a talker's utterance is slower or when the distraction is removed.

The second method for classifying disorders of the central communicational processes, as already mentioned, disregards the age factor. It separates problems of interpreting incoming messages from disturbance in linguistic integration and these, in turn, from breakdowns in expressive function. For example, one patient may show inability to respond properly to words and to thoughts either said or written to him although he retains relatively good capacity to use those words and to employ concepts when he is speaking. The converse occurs to the patient who can conceptualize incoming speech satisfactorily but whose efforts to talk result in jargon even though the speech musculature is normal. Intermediate disorders are more difficult to demonstrate because their presence may seem to be affecting the receptive and expressive functions as well.

This last classificational scheme, while of some value, is imperfect because most neurological conditions that impair the central communicational processes cause disorders that overlap the categories in the schema. Thus, the most important generalizations to be made about disorders of the central communicational processes are (1) that they cover a great range, both in their severities and in the manners in which they disturb central communicational capacities, and (2) that the details of the disruptions suffered by any single patient may be extremely difficult to determine with full accuracy.

C. *Disorders of Output*—The effector segment of the human communicative system may, for convenience, be considered to begin with the motor area (pre-central gyrus) of the cortex (Figure 1). It includes the descending tracts, the feedback loops and the sub-cortical linkages requisite to neatly synergize and control neuromuscular events. It terminates with the musculature needed to speak, write or produce other forms of message. Damages and malfunctions within this afferent system are of several varieties, each producing distinctive disruption in outgoing communication.

The great preponderance of these disorders are speech defects, and such defects are the ones which interfere most with communication. The reasons for this circumstance are two.

For one thing, the speech producing mechanism must perform particularly intricate coordination because (unlike the hands, etc.) it is composed of structures which are fused physically at the midline and must therefore carry out bilaterally symmetrical actions. The fact that these structures extend from the abdominal musculature to the facial musculature adds to the task of coordination.

The second reason that speech disorders are so predominant is the more important. We are all primarily talking beings. From very early childhood we have relied upon speech to achieve the rapid, fluid and complicated interactions with those about us that are the essence of human existence. Gesturing, at least in the major cultures of the Twentieth Century, is too indefinite to serve us importantly; and writing is a "Johnny-come-lately" skill which is too cumbersome for quick use. Thus, the person who has handicappingly imperfect speech is continuously at a disadvantage in his face-to-face relations with others.

These reasons underlie the fact that this report has restricted its analysis of breakdown in effector functions to disorders of speech.

A speech disorder may be defined as an imperfection of verbal production when the output is linguistically intact. That is, the message is acceptable, but the utterance is faulty. Such disorders may be grouped under four main headings: (1) those due to flaws within the nervous system, (2) those due to flaws in the peripheral structures producing speech, (3) those resulting from faulty learning and (4) functional disruptions arising from other causes, including physchological ones.

Notable instances of speech disorders caused by flaws within the motor nervous system are found among children with cerebral palsy. The particular nature of each cerebral palsied child's discoordination in speech depends on the locus and extent of his neurological damage; so that youngsters with athetoid involvements, for example, have different problems of muscular control than do those with spasticity. The common feature linking these children is that, because of lesions within the central nervous system, the muscular movements requisite to normal speech cannot be performed as they should be. The resulting disorders may range from a complete inability to articulate speech sounds to a clumsy mouthing of utterances.

And, of course, the motor nervous system serving speech may become impaired later in life, as when the efferent innervation to a vocal fold is destroyed or when there are degenerative diseases of the nervous system such as multiple sclerosis and Parkinson's disease.

Since in most instances of damage to the efferent nerve supply there is no known means of restoring the system, management of speech disorders arising from such damage must be primarily educative and rehabilitative. Here, patience in the administration of long training regimes is often the only key to improving speech production and, then, to maintaining that improvement.

The second type of speech disorder is also organic rather than functional, but it results from malformation or damage to the peripheral organs of speech production themselves. A talker who has such a problem emits acoustically imperfect speech because his sound generating system is not intact.

The child born with cleft palate, to take one instance, lacks the separation between nasal cavity and mouth necessary to avoid abnormal nasalization of every utterance. The consequent sound distortions may be so severe that the child may be almost unintelligible. True, surgery and/or well-fitted obturators can often largely eliminate the palatal defect, but this correction is usually not completed until after the child has learned faulty muscular habit patterns which must be unlearned through special training. Moreover, there are some youngsters for whom adequate palatal control and closure can not be achieved.

A very different organic speech problem faces the man or woman whose larynx has been removed because of cancer. Such a life-saving operation permanently diverts the breath stream so that it no longer passes through the speech cavities. The patient becomes literally voiceless. Speech can now be restored to him only by teaching him to employ a substitute sound source, such as esophageal voice, and to achieve acoustical modification of this sound by passing it through the articulator system.

From these examples it can be seen that physical restoration of imperfect speech organs is sometimes possible but that even then extensive training in speech production is ordinarily required as well.

The third and fourth types of speech disorder are closely related to one another in that they are both functional in the sense that one can not point to a lesion in either the nervous system or the motor mechanism as the cause of such a problem. The difference between the two categories is that the third type consists of disorders that are the products of faulty learning, while the fourth encompasses miscoordinations arising from less obvious causes, including psychological ones.

Within the realm of learned disorders one finds such problems as foreign dialect (provided such a dialect poses a social or economic handicap for its possessor), habitual raucous voice, habitual nasality and habitual misarticulation (such as lisping). Defects of these varieties can usually be minimized or eliminated by appropriate ear training combined with practice in correct speech production. It should be pointed out, however, that many problems presumed to be due to faulty learning are actually due to subtle neurologic deficits, such as disturbances in oral-sensory perception, lack of auditory monitoring or disturbances in the organization of sequences of speech movement.

The situation may be very complex when dealing with speech disorders of the fourth variety. For example, the speech disorder may be symptomatic of a deep-seated psychological disturbance (as in hysterical aphonia) and may require psychotherapy. On the other hand, there are cases where speech retraining may be a valuable method of treatment. A noteworthy illustration of the complexities involved is found in the problem of stuttering. Certainly, the patterns of hesitant speech that characterize the stuttering of older children and adults include many habitual incrustations, and there are experts who believe that the entire disorder can be explained on this basis. Other authorities, however, feel that stuttering is a symptom of a primary cause that is not learned. True, there is disagreement as to the presumed nature of this primary cause. Theories range from the opinion that subtle neural asynchronies are responsible to the premise that psychological maladjustment is to blame. Hence, stuttering remains an enigma while illustrating the type of disorder which does not have either a clean-cut organic cause or a clearly habitual basis.

V. Conclusion

The purpose of this chapter has been to review communication processes in general and to define the scope of human communication and its disorders as these fall within the mission of the National Institute of Neurological Diseases and Stroke. The communicative behavior of each individual is achieved by his nervous system. Thus, the Institute has interest in successive stages of this behavior from the reception of meaningful stimuli to the production of intelligible replies and in the disorders that result from damage or malfunction at any point within the sequence. The phenomena involved, both normal and abnormal, may be helpfully classified as receptive functions (hearing), central integrative functions (language) and effector functions (speech production). The remainder of this report is organized in conformity with this classification. However, we must remember that the most significant feature of human communication is that its processes are parts of a functioning totality, be those processes normal or defective. From the instant a person's ears receive meaningful sound to that instant when he replies, the activities that occur are so sequentially unified that a disturbance at any point along the way will often have effects at any other, and sometimes unexpected, points. We must be quick to appreciate the instances where segmentation such as used in this report gives us an imperfect or false orientation to human communication and its disorders.

Chapter 2—CURRENT STATUS

I. INTRODUCTION

The present chapter surveys four major areas which must be taken into account if we are to have an adequate frame of reference within which to evaluate research accomplishments and research needs. These four areas are 1) the current prevalence of communicative disorders, 2) the current costs to the Nation of communicative disorders, 3) the current magnitude and scope of research on human communication and its disorders, and 4) the current magnitude of training programs designed to prepare professional personnel in this field.

II. PREVALENCE OF COMMUNICATIVE DISORDERS

A. *Prevalence of Disorders of Hearing.* Disorders of hearing which are socially and economically handicapping are of three varieties: 1) loss of acuity so severe as to be classified as deafness; 2) loss of acuity which imposes only a partial handicap, so that the patient is classified as hard of hearing; and 3) dysacusic disturbances in which garbled hearing is the primary symptom.

1. Prevalence of Deafness. Deafness has never been defined to the satisfaction of all authorities. The most widely known and probably most widely accepted definition is the one developed in 1937 by the Committee on Nomenclature of the Conference of Executives of American Schools for the Deaf. This definition, though somewhat arbitrary in its disregard of individual variations in handicap, can serve here as a frame of reference. According to it, the deaf are defined as follows:

> Those in whom the sense of hearing is nonfunctional for the ordinary purposes of life. This general group is made up of two distinct classes based entirely on the time of the loss of hearing. a) *The congenitally deaf*: those who are born deaf. b) *The adventitiously deaf*: those who were born with normal hearing but in whom the sense of hearing becomes nonfunctional later through illness or accident.

The task of ascertaining how many deaf persons there are in this country has never been accurately performed. Even those estimates at our disposal have not determined hearing capacity with sufficient precision to separate accurately the deaf from the severely hard of hearing. The arbitrary dividing lines set up in such estimates are at best only suggestive of the differentiation. Nonetheless a rough delineation of the prevalence of deafness is possible.

Most deafness is congenital or is acquired relatively early in life, so that statistics on the number of deaf children of school age are particularly pertinent. As of October 31, 1967 there were 38,391 such children enrolled in schools and day classes throughout the country. (Directory of Services for the Deaf in the United States. *American Annals of the Deaf, 113,* 1968, 756). A noteworthy fact is that this enrollment has increased markedly in the past few years. Frisina reported the figure as 25,525 less than a decade ago. (Statistical Information Concerning the Deaf and Hard of Hearing in the United States. *American Annals of the Deaf, 104,* 1959, 265-270).

It should be stressed in connection with these figures that an unknown number of deaf children, albeit probably not a large one, were not enrolled in the educational programs covered by these tabulations. Among other things, deaf children tend to progress slowly in school, so that some are dropouts late in their grade school or early in their high school careers. This factor is at least partially responsible for the decrease in enrollees which has been noted for the upper grades. Thus, it would seem reasonable to increase moderately the estimates given by these tables and to conclude that there are approximately 40,000 deaf individuals between the ages of 5 and 18 years in the United States. Expressed in another way, this number represents a prevalence about 88 per 100,000 children in this age range.

Statistics on the prevalence of deafness in the age ranges under 5 and over 18 years are very uncertain. However, Frisina (*op. cit.,* p. 265) reports estimates made by the Rehabilitation Services Administration which can be extrapolated to indicate the approximate magnitude of our current problem. These estimates as summarized by Frisina are reproduced in Table 2-1. We have computed from these estimates the prevalences per 100,000 population. Note that the prevalence increases slightly from one decade of adulthood to the next and that the average prevalence over all ages and both sexes is estimated at 118 per 100,000. Extrapolating this value to the present population of the United States yields a conservative total of almost 236,000 deaf. Thus, almost a quarter of a million of our citizens have hearing defects so severe that everyday sounds are of very little, if any, practical use to them.

2. Prevalence of Partial Impairments. In 1935-36, the U.S. Public Health Service conducted the first large scale audiometric study of hearing impairment performed in this country. One outcome of this study was a five-fold classification of hearing loss which with minor modifications has proven valuable ever since. This classification includes two categories of severe impairment (stages 4 and 5) corresponding to adventitious and congenital deafness, respectively; while the three other categories delineate three major stages of partial handicaps. Stage 1 includes the mild impairments. It encompasses persons "who . . . have difficulty in understanding speech in church, at the theater or in group conversations, but can hear speech at close range without artificial assistance" (Beasley, W. C., Characteristics and Distribution of Impaired Hearing in the Population of the United States, *Journal of the Acoustical Society of America, 12,* 1940, 114-121). Stage 2 designates losses sufficiently greater so that the possessors have trouble hearing direct conversation at close range yet can use the telephone satisfactorily. Stage 3 represents impairments great enough so that only amplified speech can be understood. The data in hand from the 1935-36 survey revealed that each of these three stages covered a wide variety in both configuration and degree of loss, with some overlap between stages (Beasley, W. C., Characteristics of Hearing Loss in Various Types of Deafness, *Journal of the Society of Motion Picture Engineers,* 35, 1940, 59-85).

TABLE 2-1.—Estimated number of deaf in the U.S. (Frisina, "American Annals of the Deaf, 104 (1959), 265). Prevalence per 100,000 added by us to Frisina's table.

Age in Years	U.S. Pop. July, 1953	Est. Deaf July, 1953	Prevalence per 100,000
Males			
Under 15	23,148,000	15,000	65
15-24	11,075,000	9,300	84
25-34	11,910,000	10,800	98
35-44	10,992,000	11,100	101
45-64	15,994,000	20,200	126
65 and over	6,236,000	28,900	462
Total	79,354,000	95,300	120
Females			
Under 15	22,275,000	9,400	42
15-24	10,860,000	7,400	68
25-34	12,346,000	9,800	79
35-44	11,368,000	9,700	85
45-64	16,337,000	22,100	135
65 and over	7,088,000	34,400	206
Total Females	80,274,000	92,800	116
Combined Total	159,628,000	188,100	118

The 1935-36 survey did not employ sampling procedures that allowed any valid estimate of either prevalence or incidence of hearing impairments, but comparison of hearing test results with data gathered from relatives during home interviews revealed that ". . . on the average, impaired hearing is not recognized socially until the individual has attained an impairment sufficient to interfere with understanding direct conversation" (Beasley, *op. cit., JASA,* 119). Thus, because mild but handicapping auditory defects tend to be socially-hidden defects, their incidence is much greater than one would estimate from casual observation within his own circle of associates.

Since 1936 there have been four widely publicized surveys that, each in its own way, throw some light on the prevalence of hearing impairments in the United States. The first two of these were the 1939 World's Fair Study by the Bell Telephone Laboratories (J. C. Steinberg, H. C. Montgomery and M. B. Gardner, Results of the World's Fair Hearing Tests, *Journal of The Acoustical Society of America, 12,* 1940, 291-301), and the 1954 Wisconsin State Fair Hearing Survey (Glorig *et al., 1954 Wisconsin State Fair Hearing Survey,* American Academy of Ophthalmology and Otolaryngology, 1957). These two surveys suffer from not being unbiased samples, since among the adults attending these fairs, it was those adults who were interested in hearing who took advantage of the free hearing tests that were offered. The results probably show a loading of each population with persons having hearing defects. Nonetheless, some of the findings from these surveys are presented in Table 2-2. This table reports approximate prevalence percentages for threshold deficits within the conversational range which reach or exceed moderate mild impairment (stage 1) and separately, which reach or exceed moderate loss (stage 2). It also extrapolates to the numbers of hearing handicapped one would estimate from these percentages on the basis of the 1960 U.S. Census.

Two recent surveys of importance are the 1960-62 Health Examination Hearing Survey (*Hearing Level of Adults by Age and Sex, United States — 1960-1962,* National Center for Health Statistics, Series 11, No. 11, U.S. Dept. HEW, October, 1965) and the 1962-1963 Health Interview Hearing Survey (*Characteristics of Persons with Impaired Hearing,* United States, July 1962, June 1963, National Center for Health Statistics, Series 10, Number 35, U.S. Dept. of HEW, April, 1967). These two endeavors

TABLE 2-2. Estimated percentages of hearing loss reaching or exceeding approximately 41 dB (ISO 1964) and 56 dB (ISO 1964) in the conversational range of test frequencies.

These percentages were derived from data gathered during the 1939 World's Fair and the 1954 Wisconsin State Fair Surveys. The number of cases per decade was then computed from the estimated percentage for that decade on the basis of population distribution found during the 1960 U.S. Census.

	Stage 1: Average Poorer Than Approximately 41 dB				Stage 2: Average Poorer Than Approximately 56 dB			
	1939 Fair (880-1760 Hz)		1954 Fair (500-2000 Hz)		1939 Fair (880-1760 Hz)		1954 Fair (500-2000 Hz)	
Age	%	Number	%	Number	%	Number	%	Number
10-19	1.6	479,872	.5	149,960	.6	179,952	.1	29,992
20-29	1.4	303,380	3.5	758,450	.3	65,010	1.4	303,380
30-39	3.1	757,330	6.8	1,661,240	.7	171,010	2.5	610,750
40-49	7.3	1,640,967	12.1	2,719,959	1.9	427,101	4.1	921,639
50-59	13.4	2,416,824	16.8	3,030,048	3.9	703,404	4.8	865,728
60-69	no data		31.4	4,521,600	no data		12.4	1,785,600
70-79	no data		46.8	4,821,336	no data		22.3	2,297,346
TOTAL		5,598,373[1]		17,662,593[2]		1,546,477[1]		6,814,435[2]

Note: [1] Ages 10-59. [2] Ages 10-79.

TABLE 2-3. Approximate number of persons aged 18-79 years in the United States with impaired hearing for speech as estimated from average of thresholds for 500-2000 Hz in better ear. Health Examination Survey, United States, 1960-62 (Derived from Table 11, p. 28, National Center for Health Statistics, Ser. 11, No. 11).

Hearing Level (re ISO 1964)	Men	Women	Total
+37 to +56 (Circa Stage 1)	1,328,000	1,126,000	2,454,000
+57 to +76 (Circa Stage 2)	439,000	290,000	729,000
+77 to +86 (Circa Stage 3)	164,000	114,000	278,000
+87 or more (Circa Stages 4 and 5)	70,000	113,000	183,000
Total	2,001,000	1,643,000	3,644,000

were carried out by the Public Health Survey according to carefully controlled sampling procedures. In the first of these studies, estimates of prevalence were based upon hearing tests administered to 6,672 persons "... selected to represent the 111 million adults in the U.S. civilian, non-institutional population aged 18-79 years." Consequently these estimates could be expressed in quantitative terms, i.e., threshold deficits in dB. The second study derived its estimates from interviews obtained during a continuous probability sampling of the civilian, non-institutional population of the United States. Insofar as hearing data were concerned, the survey encompassed 42,000 households containing 134,000 persons covering the entire age span. In this instance, criteria of hearing impairment were qualitative, being expressed in terms of the kinds of trouble in everyday hearing that the respondents to the interviews observed in themselves and in their relatives.

Estimates from these two surveys as to the prevalence of handicapping hearing loss are reported in Tables 2-3, 2-4 and 2-5. Several general conclusions emerge from the information contained in these tables.

1. Handicapping hearing impairments are somewhat more prevalent at all age levels among men than among women.

2. As it is also apparent from Table 2-2, the prevalence of handicapping hearing impairments increases with age, and it becomes about ten times as great in the declining years of life than it is at the threshold of adulthood.

3. After subtracting out the small proportion of children and adults properly classified as deaf, there remain almost 4,000,000 persons in this country with enough threshold deficit to interfere to some degree with everyday social efficiency and about 1,500,000 with gross difficulty in understanding speech.

4. The total number of persons with practical difficulty in hearing probably exceeds by at least 50 percent the numbers just mentioned. To explain: the National Health Examination Survey did not seek out persons with relatively good thresholds in the so-called "speech range" but with auditory discrimination problems which cause speech to be "fuzzy" (dysacusis). By contrast, when we recall Beasley's observation that mild losses tend to go unnoticed by others, we may be confident that almost all of the lesser handicaps predicted by the Health Examination Survey were not reported in the Health Interview Survey. Such being the case the fact that the two surveys yielded almost the same overall prevalence (2.7 per cent), must indicate that a second group of persons with relatively good threshold levels but practical difficulty arising out of auditory dis-

TABLE 2-4. Estimated number of persons in the United States with hearing impairment for speech comprehension in one or both ears, grouped by sex and age. United States Health Interview Survey, 1962-63. (Derived from Table 1, p. 21, National Center for Health Statistics, Ser. 10, No. 35).

Sex and Age	Binaural Impairment Can Hear and Understand: Most words	 Only few words	 No words	 Total Binaural*	One ear impaired
Both Sexes					
All ages	2,439,000	736,000	855,000	4,085,000	2,469,000
Under 17 yrs.	137,000	36,000	52,000	229,000	183,000
17-44 yrs.	320,000	110,000	107,000	542,000	716,000
45-64 yrs	647,000	201,000	227,000	1,087,000	855,000
65 yrs. & over	1,335,000	389,000	469,000	2,226,000	715,000
Male					
All ages	1,446,000	378,000	419,000	2,264,000	1,302,000
Under 17 yrs.	74,000	18,000	28,000	122,000	100,000
17-44 yrs.	183,000	54,000	51,000	290,000	417,000
45-64 yrs.	439,000	126,000	117,000	686,000	445,000
65 yrs. & over	749,000	180,000	223,000	1,165,000	340,000
Female					
All ages	993,000	358,000	436,000	1,821,000	1,167,000
Under 17 yrs.	62,000	18,000	24,000	107,000	83,000
17-44 yrs.	137,000	56,000	56,000	253,000	299,000
45-64 yrs.	208,000	75,000	110,000	401,000	410,000
65 yrs. & over	586,000	210,000	246,000	1,061,000	375,000

* Includes 55,000 persons whose degree of impairment was unknown.

crimination problems were reported in the latter survey. These were the dysacusics missed by the Health Examination Survey. It is not possible to estimate how large this second group was, since no one has ever conducted the necessary testing of an appropriate population sample by both pure tone audiometry and speech audiometry. However, the fragmentary clinical clues at our disposal coupled with the kinds of discrepancy observed by Beasley between audiometric data and interview data allows the opinion that about half of the persons catalogued by either survey as having bilateral impairments were missed by the other survey. Such an occurrence would add about 2,000,000 persons to our estimate and bring to about 6,000,000 the total of persons estimated to have bilateral hearing problems of handicapping magnitude.

5. When assessing the total prevalence of hearing handicaps, one must add that about half as many additional persons (almost 2,500,000) have socially noticeable impairments in one ear (See Table 2-4). These individuals suffer different but nonetheless real difficulties, particularly in noisy places.

6. *Thus, in summary, although contemporary data remain incomplete in important ways, it is reasonable to estimate that about* 8,500,000 *Americans have auditory problems of one type or another which are less severe than deafness but which impair communication and hence social efficiency.* The majority of these individuals are in the older age groups, but about 4.5 percent (circa 360,000) are under 17 years.

A final word needs to be said regarding the prevalence of partial hearing impairments among children. Systematic data on pre-school children is lacking except as these are now accumulating from the NINDS Perinatal Project. Here the evidence is that, at 12 months of age, 10 percent of the children fail a test of response to auditory stimuli. Research which is in progress now will reveal what fraction of these youngsters have actual auditory impairment. For the moment, we must confess to ignorance as to prevalence of such impairments in the group under five years of age.

TABLE 2-5. Percentages of persons aged 18-79 years with hearing impairments as estimated by the two recent U.S. Public Health Service Surveys.

Health Examination Survey: 1960-1962		Health Interview Survey: 1962-1963	
Average Hearing Level: Better ear in 500-2000 Hz range (ISO 1964)	%	%	Speech Comprehension Group
41-55 dB: Frequent difficulty with normal speech	1.6	1.7	Can hear and understand most spoken words
56-70 dB: Frequent difficulty with loud speech	1.1	1.0	Can hear and understand a few spoken words
71-90: dB Understands only shouted or amplified speech			
91+ dB: Usually can not understand even amplified speech			Cannot hear and understand spoken words
TOTAL	2.7	2.7	TOTAL

The situation is somewhat clearer when we consider school-age children. However, two factors complicate any judgments which are to be made. The first one is that children with severe hearing defects tend to be identified early. Many are consequently drawn out of the ordinary school population and into special schools, while a few are never enrolled. The second complication is that although many local and regional surveys of school populations have been carried out, these have generally lacked sufficient rigor of sampling or have deviated sufficiently in criteria so that nationwide prevalences can not be legitimately estimated from them. The study which comes closest to standing as a useable prototype for this purpose is the Pittsburgh survey of 1958-60 which was conducted in cooperation with the American Academy of Ophthalmology and Otolaryngology. Table 2-6 represents Eagles' summary of these percentages of impairment for pure tones that were found in the age bracket from 5-10 years inclusive (The Survey, *Conference on the Collection of Statistics of Severe Hearing Impairments and Deafness in the United States,* Public Health Service Publication No. 1227, 1964, 41-44).

Eagles says of these results, "The prevalence of handicap . . . was uniform as a function of age. . . . The percentage of children with any significant handicap . . . is 1.7 percent." He cautions against extrapolating from these data to the population at large, but adds, "However, these data do tend to bear out the conclusion of Davis and Silverman that some of the estimates of numbers of hearing impaired children made in the past may be excessively high." Certainly, if the percentages of handicap yielded by the Pittsburg study are reasonably representative, one must conclude that only about one child in every 300 of primary school age has frequent difficulty in understanding loud speech, while only about one more in every hundred and twenty is seriously at an auditory disadvantage in classroom situations. Or again, in terms of population distribution revealed by the 1960 census, these percentages yield prevalence estimates of 100,000 and 250,000 children, respectively.

The overall generalization which emerges is that partial hearing impairment among school children is a problem which, though critical to the child possessing it, is not so prevalent that it is easy to mobilize groups of such children for special educational management except in larger metropolitan areas.

TABLE 2-6. Percentages of impaired hearing found during the Pittsburgh study in 4,064 school children aged 5-10 years inclusive.

Hearing levels reported as averages for 500-2000 Hz Re ISO (1964) standard. (Adapted from Tables VI and VII. E. Eagles, The Survey, *Proceedings of the Conference on the Collection of Statistics of Severe Hearing Impairments and Deafness in the United States, 1964,* Public Health Service Publication No. 1227, 1964, 43-44.)

Class or Handicap	Percent			
Less than 26 dB: no difficulty with faint speech	98.3			
26-40 dB: difficulty only with faint speech	0.9			
41-55 dB: frequent difficulty with normal speech	0.5			
56-70 dB: frequent difficulty with loud speech	0.2			
71 dB and more: educationally-deaf at best can understand only shouted amplified speech	0.05			
Cumulative percent handicapped		1.7	.8	.3

3. Prevalence of Multiple Handicaps. We know that hearing handicaps sometimes exist concurrently with other disorders. However, survey information indicates that the frequency of such combinations is sparse. The most definitive data covers the relationship to visual defects. These data come from the Health Interview Survey mentioned above. According to this survey, 5.4 percent (about 220,000) of the persons with binaural hearing impairment have severe visual impairment (cannot read ordinary newspaper print even when wearing glasses), and 12.1 percent more (490,000) were reported to have lesser visual impairments (pp. 16-17). These proportions increase with age, reaching values of 8.8 and 17.7 percent, respectively, among persons 65 years and older.

4. Prevalences According to Etiology. We do not have any information which is sufficiently broad in its coverage and controlled in its sampling to indicate prevalences of various causes of hearing impairments. Even the etiological distributions encountered in major medical centers can not be taken as representative because selective factors are always at work. For example, many persons with chronic impairment of mild degree do not seek help. Again, some diagnostic categories include a substantial number of hearing losses that are either reversible or are not severe enough to be handicapping. Other uncertainties also exist. One illustration is the fact that the prevalence of stapes fixation due to otosclerosis varies notably with both race and sex. Finally and particularly important, advances in medical science and changes in cultural patterns continuously modify the ratios of incidence and, eventually, of prevalence. Some causes for hearing loss have been greatly reduced, i.e., impairments due to otitis media and congenital syphilis; while other causes now operate more frequently, i.e., prenatal and perinatal disease which previously were more often lethal, occupational noise exposure and old age.

5. Prevalence According to Audiometric Pattern. We do not have any reliable quantitative information on the distribution of patterns of hearing loss. Such patterns, or audiometric configurations, are somewhat characteristic for each etiology. For example, conductive hearing losses due to middle ear disease are usually more severe for low pitched tones than for high pitched tones, while the deficits characterizing most sensori-neural losses are either fairly uniform or greater at higher frequencies. Individuals who have suffered combinations of two lesions, such as stapedial fixation and inner ear damage from cochlear otosclerosis, may have very bizarre audiometric configurations. Insofar as the systematic changes of hearing with age are concerned, we know that acuity for high frequencies is eroded away more rapidly than for low frequencies. To generalize: the point is that we lack, first, a university-accepted system for classifying audiometric configurations and, second, systematic exploration of the prevalence of each configuration.

6. Prevalence of Dysacusis. The prevalence of dysacusis, or the garbling of audible speech, has not been studied systematically on a large enough population to allow any generalizations regarding its occurrence in the population at large. Methods of determining dysacusis involve tests for speech discrimination which have not been rigorously administered on a mass scale. Thus, only three comments can be made at this time. First, dysacusis is often a concomitant of loss in sensitivity. Second, it can also either occur independently thereof or it may appear in conjunction with a threshold deficit too mild to be handicapping by itself. Lastly, a great many elderly persons exhibit a combination of dysacusis and a characteristic high frequency loss in sensitivity. If we include this composite presbycusic malady in our tabulation, the prevalence of handicapping hearing impariment is probably at least as high as one in four among persons over sixty.

7. Worldwide Prevalence. No reliable data are available on the prevalences of hearing disorders throughout the world at large, albeit some statistics from more advanced countries can be assembled. We may be sure, however, that in many of the less privileged sections of the world, diseases and other conditions causing hearing loss are more common than in the United States. Thus, even allowing for racial differences in proportions of impairment, the picture of prevalences as we find it for this country is probably optimistic (except as regards hearing disorders of the elderly) when we consider the world at large.

8. Summary on Prevalence of Hearing Disorders. To reiterate a few main points:

a. There are approximately 236,000 deaf individuals of all ages and both sexes in the United States today.

b. Approximately 6,000,000 Americans have partial hearing impairments of handicapping degree that are bilateral.

c. An additional 2,500,000 or so have significant unilateral losses.

d. Among school-age children there are about 38,000 in schools for the deaf, about 100,000 more requiring intensive special management and circa 250,000 more who are auditorily handicapped to an important degree in the school environment.

e. About 700,000 persons suffer a combination of at least some degree of handicapping hearing deficit and some degree of handicapping visual problem.

f. Handicapping hearing losses are particularly prevalent in the older age group and here they are more frequently combined with visual disabilities.

g. No reliable general data are available on the prevalence of hearing losses by cause, on the distribution or the patterns of losses, or on the incidence of dysacusis.

B. *Prevalence of Central Communicative Disorders.* The population of individuals with central communicative disorders, as conceived of here, is that group who fail to develop adequate language because of central nervous system dysfunction plus those persons who sustain a reduction or loss of language functioning because of acquired neurological anomalies.

One of the prime difficulties in discussing these central problems in the child population is that it is often exceedingly difficult to arrive at an unequivocal diagnosis of the language disorder. There are a host of agents which may lead to inadequate development of language skills. Among the most frequently cited causes are deafness, mental retardation, specific language disability ("childhood aphasia") due to minimal cerebral injury, and severe emotional disorders. It is not at all uncommon to find that the child with inadequate language development shows evidence of multiple handicaps, including not only the aforementioned factors, but also others such as neuromotor defects, perceptual handicaps, epilepsy, and learning disabilities.

Because of these diagnostic difficulties, most of the available information concerning the incidence of central communicative disorders is very gross. In most cases, one can be reasonably confident that individuals with profound deafness have been excluded. But other contributing factors probably vary greatly from child to child within the groups studied.

The ASHA Committee on the Midcentury White House Conference (Speech Disorders and Speech Correction, *Journal of Speech and Hearing Disorders, 17,* 1952, 129-137) estimated that 3 percent of our children are retarded in speech development. If we assume that there are some 50,000,000 individuals in the United States today between ages of 5 and 21, this yields a prevalence of 600,000. A higher percentage was cited by Pronovost (A Survey of Services for the Speech and Hearing Handicapped in New England, *Journal of Speech and Hearing Disorders, 16,* 1951, 148-156), in a compilation of speech surveys made in New England. Out of 87,288 persons evaluated, 548 were reported to have delayed speech. This constituted .6 percent of the total group. On the basis of this admittedly scanty data, it would seem reasonable at this point to set the overall prevalence of developmental failures of language at roughly one case per 170 children. It must be emphasized, however, that there is probably a considerably higher prevalence of more subtle communicative disorders. The figures given above refer to a population where speech development is grossly and obviously retarded. Recognizing that language functioning is one of the most labile of human capacities, and considering the fact that the Perinatal Research Project being carried out by NINDS has reported that by one year of age, 12-15 percent of children show neurological abnormalities, it is reasonable to assume that really careful evaluation of a large population of children would show a considerable prevalence of central language problems. Specific involvement of reading processes (dyslexia), for example, may involve as many as 3 percent of our school-age children. The Perinatal Research Project will provide valuable data on the prevalence of related disturbances.

Aphasia is the primary entity responsible for central communicative disorders in adults. It is most often due to vascular lesions, cerebral trauma, or tumors. Of sixty patients included in the now-classic studies of Weisenberg and McBride (*Aphasia: A Clinical and Psychological Study.* New York: Hafner, 1964, reprinted), 37 had aphasia of vascular origin, 8 had suffered cerebral trauma, and there were 15 trauma cases. During time of war, of course, there is an expected increase in the number of trauma cases. Undoubtedly, the increasingly rising number of accidents on our high-speed highways have also added to the proportion of trauma cases. Nevertheless, cerebro-vascular accidents continue to be the most important single cause of adult aphasia.

The report of the Joint Council Subcommittee on Cerebrovascular Disease of NINDS and the National Heart Institute (1965) indicated that the Nation's population included at least 2,000,000 individuals who had survived strokes. No reliable data are available concerning how many of these individuals might be aphasic. But a reasonable estimate can be formulated. Because an overwhelming majority of individuals show a cerebral dominance for language in the left cerebral hemisphere, strokes affecting the right hemisphere (often causing left-sided paralysis) will usually not result in permanent language disability.* Furthermore, left-sided damage (often causing right-sided paralysis) may spare those cerebral areas seemingly critical for language competence. Considering these facts, then, it seems reasonably conservative to estimate that perhaps 20 percent of the stroke population have aphasic sequelae. This would lead to an estimate of 400,000 aphasic survivors of stroke. When we add to this the number of individuals whose language disorders are due to tumor or to traumatic accidents, an estimate of 600,000 aphasic American adults would not seem unrealistic.

In summary, central communicative disorders of significance plague a large number of Americans. An unknown number of children, but certainly not less than 1,500,000 have disorders due to neurological involvement ranging from retarded speech to learning disabilities involving linguistic processes, while about half as many adults suffer aphasic sequelae to neurological insult or disease. Thus, the Nation's total of central communicative disorders is of the order of 2,100,000.

C. *Prevalence of Speech Disorders.* Like disorders of central language processes, current knowledge of the prevalence of speech disorders is not satisfactory. Though there have been numerous surveys undertaken, these have had limited value because the classification systems used have varied greatly and because criteria for discriminating defective speech from normal speech have rarely been defined objectively. Furthermore, it is important to consider that the adequacy of an individual's speech behavior cannot be determined without reference to social milieu. Certain articulatory patterns, such as use of "dese" and "dose" for *these* and *those,* may be characteristic of a socio-economic or geographic group; such "deviations" may be normal within the restricted dialectal community. In a different setting, however, the same speech behavior might very well constitute a serious social and economic handicap, and thus it becomes reasonable to consider the individual's speech to be defective. Variations in vocal quality are likewise normal according to varying environmental standards. The

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* It is now clear that even those cases not considered aphasic may show subtle deviations of language and thought when examined by appropriate methods. These impairments may be of no consequence to a majority of patients; but for those whose work requires a high level of language competence—persons in education, government, law, etc.—these problems may be grave.

"nasal twang" which is characteristic of some American dialect regions would constitute a voice disorder in other regions. Recognizing that the available figures are of limited reliability and validity, this section will review data on the prevalence of disorders of speech. Many of the sources cited here have been reviewed and summarized by Milisen in Travis' *Handbook of Speech Pathology* (New York: Appleton-Century-Crofts, 1957).

Little direct information is available on the incidence of speech disorders in the general population; however, several surveys of school children have been reported. The White House Conference of 1931 reported that 7 percent of 10,033 school children in Madison, Wisconsin had defective speech. This figure was based on evaluations made by speech pathologists. It was consistent with the report of a median percentage of 6.9 percent from a questionnaire survey of 48 cities. The individual cities showed widely discrepant figures, however, ranging from 1.0 per cent to 21.4 per cent. In his review Milisen cited several other speech surveys of the school-age population, and the reported percentages of children with speech problems ranged from 6 to 33 percent. For example, a large scale survey of speech handicapped individuals in New England was reported by Pronovost. Of 87,288 persons tested, 12,565 were reported to have some kind of speech disorder. This constituted 14.4 per cent of the population examined. Table 2-7 gives figures concerning the frequency of occurrence of different problems within this group.

TABLE 2-7. Frequency of occurrence of speech disorders in a population of 87,288 New England individuals (from Pronovost, "Journal of Speech and Hearing Disorders," 16 (1951), 148-156).

Type of Speech Problem	Number	Per Cent of Total Disorders
Articulation	6,282	50.0
Voice	827	6.6
Delayed Speech	548	4.4
Cerebral Palsy	132	1.0
Cleft Palate	154	1.2
Hard of Hearing	1,936	15.4
Deaf	1,057	8.4
Stuttering	1,363	10.9
Aphasia	58	0.5
Miscellaneous	208	1.6
Total	12,565	100.0

Morley reported on a survey of university students at one Midwestern university. (A Ten-Year-Survey of Speech Disorders, *Journal of Speech and Hearing Disorders*, 17, 1952, 25-31) His figures are of interest, because they are limited to a young adult population in which experience and maturation have not been sufficient to normalize speech. As Table 2-8 shows, 33,339 individuals were tested during this period, and 1,220 were judged to require clinical services. The fraction of speech defective students was 3.8 percent. Even within this restricted population, considerable variance is noted year to year, as witness the occurrences ranging from a low of 1.7 percent to a high of 8.0 percent. It seems likely that at least some variability derived from different criteria of defectiveness used by different examiners.

Morley's data are also of interest with regard to the distribution of types of disorders. As would be expected, articulation cases constituted the largest single sub-group, 50.70 percent. The remainder of the clinical population was made up of stutterers (25.48 percent), voice cases (15.04 percent), and miscellaneous cases (8.75 percent). With the exception of three years, this rank order of problems by prevalence was consistent over the ten years for which figures were reported.

It seems apparent that the great variability in prevalence figures suggested by the foregoing paragraphs is due primarily to use of different criteria for designating a person as a defective speaker or as a normal speaker. Indeed, some surveys have given prevalence figures for all speech disorders, but then have gone on to report smaller prevalence figures for the "serious" problems.

A conservative and reasonable set of estimates was reported by the ASHA Committee on the Mid-century White House Conference (*op. cit.*). This Committee's estimate was that 5 percent of the total population of the country has some type of speech defect. Based on the population of 150,000,000 at that time, with an assumed population of 40,000,000 individuals between the ages of five and twenty-one, they reckoned that there were 7.5 million persons in the United States with defective speech, and that 2 million of these were between the ages of five and twenty-one. Table 2-9 gives the Committee's estimates of the percentage of prevalence of various types of disorder. When extrapolated to our present population of 200,000,000 we are led to conclude that there are now 10,000,000 speech defective persons in the country, and that 2,50,000 are between five and twenty-five years of age.

The prevalence of speech disorders according to type that appears in Table 2-9 is provocative. Functional articulatory disorders predominate, constituting three-fifths of all disorders and totaling 6,000,000 cases. Stuttering is a strong second (i.e., one seventh of all disorders and 1,400,000 cases). Every tenth speech disorder is associated with, and may be considered primarily due to, impaired hearing. The remaining kinds of disorder are less common, but they include a substantial fraction of speech dis-

TABLE 2-8. Speech disorders in a college population over an eleven-year period (compiled from Morley, "Journal of Speech and Hearing Disorders," 17, 1952, 25-31.)

Year	Total Examined	Defective		Articulation		Stuttering		Voice		Misc.	
		No.	%	No.	%	No.	%	No.	%	No.	%
1941	3.220	257	7.98	119	46.30	31	12.06	67	26.07	40	15.56
1942	3,095	161	5.20	94	58.38	35	21.73	32	19.87	0	0.00
1943	2,264	121	5.30	76	62.80	20	16.52	18	14.87	7	4.78
1944	2,251	68	3.02	30	44.11	26	38.23	6	8.82	6	8.82
1945	2,836	151	5.32	82	54.30	29	19.20	16	10.59	24	15.89
1946	4,432	101	2.30	49	48.51	22	21.78	20	19.80	10	9.90
1947	3,469	118	3.40	64	54.23	37	31.35	11	9.32	6	5.08
1948	4,357	75	1.70	36	48.00	24	32.00	10	13.33	5	6.66
1949	3,700	48	1.29	19	39.58	16	33.33	8	16.66	5	10.41
1950	3,362	107	3.18	51	47.66	25	23.36	28	26.16	3	2.80
1951	353	13	3.68	7	53.84	4	30.76	0	0.00	2	15.38
TOTAL	33,339	1,220	3.85	627	50.70	269	25.48	216	15.04	108	8.75

abilities resulting from organic malformation or lesion. True, one can not say how many cases of retarded speech development or of voice disorders have organic cause, but it is at least clear that all persons with cleft palate speech or with dysarthric speech related to cerebral palsy do have an underlying organic defect. In the cases of these latter maladies, although the prevalence is not as large as with some of the other disorders, the disruption of communication is often drastic, and human need for full attack on these communication problems is paramount.

In interpreting the foregoing prevalence figures, it is important to kep in mind the qualification stated by the ASHA Committee:

> It is to be stressed that the figures are presented as the lowest defensible estimates. . . . They leave out an estimated additional 5 percent, or 2,000,000 children [1] who have relatively minor speech and voice defects, unimportant for most practical purposes but serious in their effects on personal and social adjustment in some cases, and obviously significant for fields of work, such as teaching, requiring good speech. (*op. cit.*, 129).

As a final note on the prevalence of speech disorders, it should be pointed out that all surveys which have reported the prevalence of speech problems for different ages or grade levels have shown an obvious reduction in the number of speech-defectives from lower to higher age or grade. Milisen (*op. cit.*, 250) has summarized these findings as follows:

> From kindergarten through fourth-grade level, roughly 12 to 15 percent of the children have seriously defective speech. In the next four grades, between 4 and 5 percent are seriously defective. General estimates above the eighth grade are based on highly selected samples and therefore the best guess would be about the same as for the upper elementary grades — 4 to 5 percent. . . . This Statement is justified by studies of specific disorders which show that little or no change takes place in the speech condition after the child has reached 10 to 14 years of age, unless special therapy is offered.

TABLE 2-9. Estimated prevalence of speech defects in the United States.

Percentages based on the report of ASHA Committee on the White House Midcentury Conference (*Journal of Speech and Hearing Disorders*, 17 (1952) 129-137). Numbers of cases have been updated; figures given here being estimated in terms of 50,000,000 between ages of 5 and 21 years and in terms of 200,000,000 total population (assuming same percentages of speech problems among children).

Type of Speech Problem	Ages 5-21 years		All Ages	
	Percent	Number	Percent	Number
Functional Articulatory	3.0	1,500,000	3.0	6,000,000
Stuttering	.7	350,000	.7	1,400,000
Voice	.2	100,000	.2	400,000
Cleft Palate Speech	.1	50,000	.1	200,000
Cerebral Palsy Speech	.2	100,000	.2	400,000
Retarded Speech Development	.3	150,000	.3	600,000
Impaired Hearing (with Speech Defect)	.5	250,000	.5	1,000,000
Total	5.0	2,500,000	5.0	10,000,000

D. *Summary on Prevalence of Communicative Disorders*. Data on prevalence of communicative disorders are incomplete and often lacking in rigor. Nonetheless, in the preceding discussion we have reviewed and interpreted these data to the best of our ability. The outcome, considering only the grand totals emerging from our analysis, is that about 8,500,000 Americans have either bilateral or unilateral hearing impairments of handicapping magnitude; another 2,100,000 have central communicative disorders; and 10,000,000 have speech disorders. We probably should assume modest overlap in these totals, but we must still recognize that approximately 20,000,000 persons in this country have communicative handicaps worthy of our concern. Moreover, at least a third (about 7,000,000) suffer either substantial or severe educational, social and economic disadvantage. Finally, approximately one-fifth of the grand total (about 4,000,000) consist of persons under 21 years of age.

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[1] This figure would now be appreciably higher because of the population growth since the Mid-Century White House Conference on Children and Youth.

III. COSTS OF COMMUNICATIVE DISORDERS

A. *Costs of Disorders of Hearing*. The costs of disorders of hearing are of three varieties. First, there are direct expenditures for education of the acoustically handicapped, for preparation of specialists to deal with these problems, for therapeutic measures and for special devices such as hearing aids. Second, there are the indirect costs hidden in reduced earning power. Third, there are those intangible prices imposed by more difficult, and consequently often less effective, social interactions and adjustments. Inter-personal life and many kinds of experience are curtailed by deafness and hearing loss.

1. Direct Expenditures. The national total of direct expenditures made necessary by disorders of hearing is hard to estimate, but the following discussion will give some idea of the magnitude involved.

a. Education of Children. First, look at the annual bill for educational programs for deaf and severely hard of hearing children. There is no way of knowing exactly what these costs are because the data available differ and not every type of facility which offers education for such children is tabulated in the *American Annals of the Deaf*, which is our best source of information on this topic. However, the facts which this publication does offer us give the basis for at least a rough estimate. Consider the figures available in the May, 1968, issue of the *Annals*. These figures cover data to October 31, 1967. At that time there were 67 public residential schools for the deaf. These schools had a total enrollment of 18,926 pupils (including 855 college-age students in Gallaudet College). The annual average cost per pupil was $2,910.93, yielding a total expenditure of $55,092,261. Capital outlay totalled $14,937,456 for the year under consideration. Comparison data are not available on the per-pupil cost for the 1,334 students concurrently in private residential schools, but conservatively assuming the same cost per pupil as in public residential schools, these students added $3,883,181. There were 17,722 more pupils listed as enrolled in 548 day school programs. Per-pupil costs are not available here either, but these programs employed 3,265 persons on their educational staffs, and salaries averaged $7,409 for a total of $24,190,385. The newly established National Technical Institute for the Deaf has enrolled its first class of 70 students and has an operational budget of about $1,500,000 for Fiscal Year 1969.

The foregoing figures total $99,603,283. They do not include: 1) many pre-school programs, 2) some programs for school-aged children, 3) some overhead charges, 4) most transportation costs and 5) sundry other items. Hence, it is reasonable to conclude that the Nation's bill for educating its young people with severe acoustic handicaps is at least $105,000,000 yearly, and that it is probably considerably more than this amount.

Information on the expense of special training for moderately hard-of-hearing children is very elusive. Often such programs retain the children in regular public school classes, which are supplemented with a few hours per week of individualized help from an itinerant specialist in communicative skills. This person very frequently also conducts speech therapy for other children in the same schools. Typically, local school districts receive reimbursement from their state government for a substantial portion of the extra costs involved, but the pattern for such reimbursement differs across the country. Illinois offers an illustration of the system where the state absorbs portions of the salary of each special teacher. The state pays $3,500 toward salaries when the teacher is working with school-aged children and $5,000 when she is working with preschoolers. In 1964-65, there were 1,538 Illinois pupils enrolled in 176 regular and pre-school classes for which the reimbursements to local districts was $604,976. (Page R., *Special Education: Directory 1965-1966, and Statistical Report 1964-65*), Springfield, State of Illinois, 1966.) Translating these figures into per-pupil costs ($389) and remembering that local school districts bore some of the extra expense, one may safely conclude that the total extra cost per pupil was approximately $500 annually. Taking these reimbursement figures as a rough guide, but reducing them by $100 to obtain a conservative nationwide figure, one may reason that the average added educational cost per child with moderate hearing loss is about $400 per year. Of course, many such children are not in schools where special help is available, but at least 50,000 probably are. In such event, the annual excess cost for these pupils may be estimated as being approximately $20,000,000. (This figure would be at least doubled if all children needing this type of special help were receiving it.)

Another education expense is the indirect one of preparing special teachers for work with children having auditory impairments. For example, approximately $2,752,000 was spent through the Office of Education during Fiscal Year 1967 to support programs for training teachers of the deaf.[1] The Office of Education also administers the funds allocated by Congress to prepare professional personnel to work with children who are hard of hearing and speech handicapped. During Fiscal Year 1967, some $2,619,000 were expended for this purpose. Concurrently, the Children's Bureau of the Welfare Administration supported several conferences and also training grants on speech and hearing handicaps at five schools. Information is not available as to the fraction of the above mentioned funds for speech and hearing which was expended in preparing people to work with hard of hearing children, but assuming it to be 25 percent of the total amount, this fraction would come to about $110,000. Combining this estimate with the sum devoted to preparing teachers for the deaf yields a total of about $2,700,000.

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[1] This amount as well as the other expenditures by the Office of Education, the Children's Bureau and the Voca-

Another activity of the Office of Education is the preparation of captioned films for the deaf, which in Fiscal Year 1967, had an allocation of $2,800,000.

In summary, the annual expense of conducting formal educational programs for acoustically impaired children and of assuring a supply of special teachers to meet their needs is at least of the order of $130,000,000 annually.

b. Services for Adults. First there is special job training and vocational rehabilitation. One may estimate that about $4,500,000 was expended during Fiscal Year 1967 by the Vocational Rehabilitation Agency, HEW, to help about 4,100 deaf adults and an additional $9,500,000 to assist about 8,600 hard of hearing adults. Since individual States expended at least as much again, the special job training and rehabilitation for the acoustically handicapped in 1967 came to at least $28,000,000 in State and Federal funds.

The second category consists of the program which the Veterans Administration maintains for the 75,000 or so cases of service-connected hearing loss. These individuals receive about $45,000,000 annually in disability compensation. Veterans Administration is currently spending about $1,000,000 for hearing aids and their maintenance. This agency also maintains 28 centers where special audiological testing, rehabilitative training and hearing aid selections are offered. The cost for staffing these centers is about $780,000.

By the time one adds to the foregoing figures the lesser expenditure of several other State and Federal agencies for deaf and hard of hearing adult care, it is reasonable to place Federal and State expenditures to supply services for these persons (exclusive of compensation for military disability) at substantially more than $30,000,000.

In addition, about $1,204,400 were expended during Fiscal Year 1967 through the Vocational Rehabilitation Administration to prepare persons to work professionally with deaf and hard-of-hearing adults. This expenditure included $551,000 for 8 teaching grants and 81 traineeships in the area of rehabilitation of the deaf. Moreover, approximately $633,400 was spent for rehabilitation of the hard of hearing. This latter figure is estimated as about 20 percent of the $3,267,000 which Rehabilitation Services Administration allocated to 61 teaching grants and 678 traineeships in the combined area of speech and hearing.

Another major aspect of service is represented by hearing clinics and other special service facilities which are maintained privately and/or locally for both adults and children with auditory handicaps. There are, for example, some 165 community hearing and speech centers in cities throughout the country (*American Annals of the Deaf*, *op. cit.*, 1968). These centers vary widely in the sizes of their staffs and in the scopes of their activity. Definitive data on their budgets is not available; but a conservative estimate is that, on the average, such a center spends $22,500 a year on its audiological activities. On the basis of this estimate, the total cost of the hearing services offered by community centers is at least $3,600,000 annually.

Three hundred sixty-three additional speech and hearing clinics function throughout the country. The auspices under which these latter clinics operate vary, most being in medical schools, in colleges and universities, in hospitals, and schools for the deaf, the remainder being privately operated. Assuming that these clinics have average annual budgets for non-medical hearing services of $18,000 per clinic, the additional expenditure is at least $6,000,000 yearly.

Persons with disorders of hearing seek help from various medical specialists, particularly otolaryngologists and pediatricians. There is no way of knowing the costs of the diagnosis and treatment (including surgery) thus received, but a figure that probably is "in the ball park" is $80,000,000 yearly.

The expenses of purchasing and maintaining hearing aids are in addition to the medical and audiological services mentioned above. Knowledgeable executives within the hearing aid industry report that about 400,000 new instruments are sold per year and that the average retail price per unit is $275, which totals about $110,000,000 in sales annually. One may extrapolate from the 1962-63 Health Interview Survey (Table 14, *op. cit.*) to the conclusion that there are about 900,000 hearing aid users in the country at the present time. This means

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tional Rehabilitation Administration have been estimated from data on programs in speech, hearing and language reported at the 1968 hearings of a Subcommittee on Appropriations of the Committee on Appropriations, *Part 2*, House of Representatives, United States Congress.

that users average about two to three years between purchases of hearing aids. Repairs between purchase cost about $9,000,000, while batteries and accessories for the entire 900,000 units cost about $15,000,000 per year. Thus the Nation's bill for hearing aids, after one subtracts out the fraction which are procured and maintained through government channels already mentioned, approaches $132,000,000 every twelve months.

Much concern over occupational deafness due to noise exposure has been voiced during the past two decades. The fears have been two-fold. One was that large numbers of employees in our heavier industries would suffer noise-induced hearing losses of handicapping magnitude. The second fear was that so many of these workers would be awarded compensation for their losses that the sums which would have to be paid would reach astronomical proportions. In 1960 Glorig said, "Our analyses indicate there are approximately 4½ million men with losses greater than 15 dB in the speech frequencies. Assuming 10 percent of these men will file for compensation on the basis of the Wisconsin formula, and that the average claim amounts to $1,000, the cost would be $450 million." (Glorig, A., Noise—Mountain or Molehill, *National Safety News*, 81 (1960), 26-ff).

For a variety of reasons this dire prediction has not come to pass; and, to date, the annual costs for occupational and accidental deafness appear to be modest. True, there is much secretiveness in this realm and accurate figures can not be obtained. There are reports that one New Jersey corporation has paid $1,000,000 in claims and another paid $250,000 (Sataloff, J., How to Sell Top Management on Hearing Conservation, *Occupational Hazards*, 28, 1966, 23-27). Moreover, there are substantial backlogs of claims in some areas; i.e., one insurance company has on file $1,000,000 in such claims in a single state from employees of only one major airline. However, payments seem to have been relatively low. In Wisconsin, for example, only $22,500 in claims, including self-insured, were awarded during 1965, the latest year for which the Industrial Commission has released information (Personal communication, Roger Maas). Likewise, the U. S. Department of Labor recently estimated that paid claims in the entire country totaled about $163,000 per year. (*Safety Standards*, U.S. Department of Labor, March-April, 1964). Thus, the situation is one where present costs of this type are low but where they may balloon quickly because of both the many claims now outstanding and the prospect of numerous new filings.

Industry has a second type of expense in dealing with industrial hearing loss. This is the expense of maintaining programs of hearing conservation and noise control. Very many companies now conduct such programs. The size of this bill, too, is nebulous. A conservative estimate, even though it is only a guess, is that industrial programs to conserve hearing cost at least $4,000,000. In round numbers, then, the combined cost of payment for claims against industry and for hearing conservation programs probably comes to about $4,200,000 annually.

By way of general summary, Table 10 assembles the various figures presented in the preceding paragraphs. These amounts represent our best estimates of the annual national outlay for the obvious direct costs of handicapping hearing impairment. The total for these several items, which the Subcommittee recognizes as doing no more than indicating the approximate minimum magnitude of these costs, is $410,445,000.

2. Indirect Costs. The indirect financial burden of hearing impairment is due primarily to reduced earning power. Here sharp distinctions must be made between persons deaf since childhood, persons with partial but handicapping hearing loss since childhood, and persons whose hearing disorders appeared later in life.

There are studies which suggest that early deafness need not be economically handicapping. Lunde and Bigman found the median individual income of 10,101 deaf adults to be $3,465, a figure which compares favorably with a median of $2,818 for persons 14 years of age and older in the general population (Lunde, A. A. and Bigman, S. K., *Occupational Conditions among the Deaf*, Washington, D.C., Gallaudet College, 1966). Men's earnings were above women's partly due to dissimilar occupational concentrations. The wages of non-whites were lower than those of whites.

The foregoing statistics are obviously deceptive when one remembers the long programs of spe-

TABLE 2-10. Estimates of annual direct costs to the Nation for the education, management and compensation of the hearing impaired.

	Approximate Cost
Public Residential Schools for Deaf	$55,092,000
Private Residential Schools for Deaf	3,883,000
Special Day Programs for Deaf and Hard of Hearing	24,190,000
Special Services in Regular Schools	20,000,000
Preparation of Special Teachers	2,700,000
Captioned Films for the Deaf	2,800,000
Vocational Rehabilitation	28,000,000
Preparation of Rehabilitationists	1,200,000
Compensation for Military Disability	45,000,000
Audiological Services for Veterans	1,780,000
Community Hearing and Speech Centers	3,600,000
Speech and Hearing Clinics	6,000,000
Private Medical Care	80,000,000
Hearing Aids and Their Maintenance	132,000,000
Industrial Claims and Hearing Conservation	4,200,000
	$410,445,000

cial education and the intensive vocational training which the early deaf typically receive. Comparable educational efforts directed toward children with normal hearing would yield a population sharply superior to the Nation's median in earning power. Thus, the base of reference for judging the economic disadvantage attending a severe hearing impairment awaits definition. Meanwhile, however, a few qualitative comments help define the boundaries of the problem. Persons who have been deaf since childhood are for the most part employed either in occupations they learned while in schools for the deaf or else in occupations that are relatively menial. Many of the older individuals were taught trades which are becoming archaic and are not now greatly in demand. Recent VRA-sponsored studies in the New England and the Southwestern States yielded the following conclusions:

> The most significant findings to emerge from these investigations was documentation of the fact that the deaf, as a group, were not receiving vocational training of a type which would prepare them to compete for or retain jobs in the present-day labor market. Much of their present training was for jobs that are rapidly being eliminated by automation (1967 Hearing before a Subcommittee of the Committee on Appropriations, House of Representatives, United States Congress, 985).
>
> . . . how best can the deaf be helped to secure and keep jobs in spite of the fact that their traditional entry jobs in industry are rapidly being eliminated? The deaf themselves ask whether they can ever realistically hope for job advancement and promotion or whether they must confine their goals to low level jobs and menial tasks at present (*op. cit.*, 977).

Granting that programs of vocational training in schools for the deaf are being extensively modernized, it is fair to say that most deaf persons are in occupations that fall below the level they would have attained after comparable training had they been able to hear. A relatively small proportion of them, for example, achieve notable success in the professions or the higher echelons of business. Moreover, there are many occupations that are essentially closed to them, i.e. radio announcing, music, etc. The earning power of the deaf as a group has suffered accordingly.

Considering all the factors just reviewed, it is reasonable to assume that their financial loss averages $1,500 annually. Estimating that 60 percent of the 232,000 deaf in this country are either working or wish to work, this average loss multiplies to an annual deficit in income of about $200,000,000.

The person with substantial loss but with useable hearing since childhood is not as severely restricted in occupational outlook as the deaf person. However, he finds his educational progress more difficult than if he were not thus handicapped. Assuming by extrapolation from the prevalences postulated earlier in this chapter that there are 600,000 such individuals in the labor force and that their extra educational problems are eventually responsible for an average deficit in earning power of $750, the annual loss for this entire group is approximately $450,000,000.

Hearing losses that occur from later childhood through adulthood tend not to be so financially disruptive. For the most part these hearing losses do not become extreme, and amplification can do much to overcome the handicap they impose. Moreover, the individuals involved have either entered their life's work or are fairly well pointed toward a final occupational level. Thus for most of these people, their hearing losses are burdens which make their jobs more difficult but that do not keep them from performing these jobs. Raises, promotions and other opportunities for advancement may be fewer—but the important point is that for most of these individuals, economic life is not disrupted. Only a minority finds it necessary to change occupations and accept work at a lower pay level. To be sure, subtle factors are undoubtedly often at work. Thus, the Health Interview Survey (*op. cit.*) revealed that persons with binaural hearing loss are over-represented, re the population at large, in the lower income categories. This observation suggests that auditory impairments tend to lower earning power. Certainly there are instances where deteriorating job performance and eventual loss of job occur. But we must recognize that radical reduction in earning power is not the typical outcome of partial hearing loss occurring in adulthood. Thus, for the purpose of the present discussion, we may consider the average income loss in this group to be about $300 per year. Estimating 2,000,000 such individuals in the labor force, the total is $600,000,000 yearly.

Table 2-11 summarizes the foregoing figures. One notes that the total loss in earning power due to hearing disorders comes to an estimated $1,250,000 annually. When one adds to this more than $415,000,000 in direct costs from Table 2-10, the grand total exceeds $1,665,000,000. This is a staggering sum for the Nation to be paying because of disorders arising only in the input segment of the human communicative system.

3. Human Travail. Of course, the great cost in dollars which hearing disorders impose can not be allowed to overshadow the price in human suffering which these disorders also exact. Here it is very difficult to describe the facts without seeming bent upon exciting emotions. But the truth is that patterns of human life are such that a severe hearing

TABLE 2-11. Estimated annual deficits in earning power among the acoustically impaired.

Category	Estimated Number in Labor Force	Estimated Average Deficit in Earnings	Approximate Total Deficit
Persons deaf since early childhood	133,000	$1,500	$200,000,000
Persons hard of hearing since early childhood	600,000	750	450,000,000
Persons hard of hearing after childhood	2,000,000	300	600,000,000
Approximate Total Deficit			$1.250,000,000

impairment can not help but be a deep personal tragedy—often the more so because others lack full awareness of its existence, and hence tend to be intolerant of it. A wise man once remarked that hearing impairments do not arouse our sympathy as they should because they are invisible and no one dies of them.

There are two critical facts which we must recognize. First, the acts of talking and of understanding the talking of others are the very core of gregarious life as we human beings know it. Second, the auditory system must be functioning effectively for response to the speech of others to go on unimpeded and, in the case of very young children, for the act of talking to be learned normally. Thus, a handicapping hearing deficit cuts into functions that are at the core of human life.

Consider, for example, the following description of the complex problems facing deaf people:

> Many of them are without useful speech despite years of training. Many have limited language skills. They receive messages primarily through their eyes. They send messages by combination of signs, gestures, speech and writing. Most of them have normal strength, mobility and intelligence. They strive for achievement within the limitations society imposes in the face of their inadequate verbal communication. This is the handicapping base of their disability. It is primarily psycho-social. It manifests itself in many ways: under-involvement in the mainstream of community life; limited sharing with fellowmen; lack of acceptance among neighbors, employers and fellow employees; severe underemployment. (1967 Hearing before a Subcommittee of the Committee on Appropriations).

The problems of the hard of hearing are somewhat different. They are less dramatic but nonetheless *very* real.

These situations being as they are, *who can properly assess the price in human values of being isolated by an auditory disorder from one's family and associates?* (Certainly not the Subcommittee preparing this report.) Here is a task which must take into account infinite ramifications. Therefore, suffice it to conclude with the observation that even if hearing impairments did not carry any dollar cost they exact a psycho-social price from their possessors which the humanitarian philosophy of our Nation can not tolerate.

B. *Costs of Central Communication Disorders and of Speech Disorders.* There are no definitive data available concerning the cost to the Nation either of central disorders of communication or of speech disorders. Therefore, the information presented in this section should be considered as merely suggestive of the magnitude of the prices these disorders exact.

1. Direct Expenditures. The largest single subpopulation we must consider are our speech and language handicapped school children. It has been previously pointed out that there are probably some 2,500,000 persons between the ages of five and twenty-one years of age who have serious speech and language problems. Eliminating from this group an estimated 500,000 not enrolled in the schools, we may conclude that our school systems are responsible for the speech and language habilitation of some 1,750,000 children.

What is the additional educational cost of providing therapeutic services to this large group? We may approach a reasonable estimate by taking the State of Illinois as an example. In Illinois, local expenses for paying the salaries of speech and language clinicians are partially defrayed by the state. The current formula is that the state reimburses the local community $3,500 for each clinician. In 1965, the salaries of 725 speech and language clinicians * in Illinois were paid in part by the State. The total reimbursement was $1,978,433. Since there were 74,843 children in Illinois who received special speech and language training in 1965, the average additional cost per pupil comes to approximately $26. The State reimbursements take care only of approximately one-half of the salary costs for speech and language personnel, however. The total additional expense for educating a child with a speech and language handicap in Illinois thus comes to about $52 per year. This figure does not, of course, include the costs for special facilities, teaching materials, and equipment which the special personnel requires to do its job effectively.

Let us now consider the national cost for the 1,750,000 children who need speech and language training. If we reduce the Illinois figure of $52 per pupil to $40 per pupil to reach a conservative nationwide estimate, we may conclude that some $70,000,000 per year are required to meet the speech and language needs of our children. One may argue that this figure is too high, since Illinois has one of the most extensive speech correction services in the Nation. We must consider, though, that in States where there is less availability of services, parents will have to seek sources of assistance outside of the school system. Be it through private therapy, therapy in a community or university clinic, or in a rehabilitation center, the costs of such special assistance will far exceed the $40 per year estimate for speech work in the schools. A recent survey of rehabilitation centers, for example, sets a median cost of $7.28 per hour for speech therapy services. For even one hour of therapy per week, the cost over a 40-week school year would be $291.20 per child. Private therapy would be still more expensive. We must also consider the costs to the Nation of those individuals who do not receive the speech and language help they require. Though no figures can be cited, it seems apparent that the ultimate costs in terms of economic liability—not to mention psycho-social costs—are staggering. With such considerations in mind, the above estimate of $70,000,000 per year to meet the needs of our speech and language handicapped school children is probably highly conservative.

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* It is worthy of note that speech therapy personnel numbered more than any other special education group with the exception of teachers of the educable mentally handicapped.

We must now consider the costs to the Nation of those communication problems which strike our adult population. The largest single sub-group here is composed of aphasic survivors of stroke. The costs of cerebral vascular disease are enormous. The President's Commission on Heart Disease, Cancer, and Stroke reported that in 1962, the total economic cost of strokes was $1.1 billion. Stroke, causing disability and premature death, resulted in a loss of 179 million man hours, or $700 million in 1962. The cost of diagnosis, treatment, and rehabilitation amounted to $440 million. To determine how much of this amount was devoted to the aphasic patients, we must recall that about 20 percent (400,000) of our stroke population have aphasic sequelae. This gives us a figure of $88 million yearly for diagnosis, treatment and rehabilitation of the post-stroke aphasic patient. Certainly the larger part of these costs is for medical treatment and for physical rehabilitation. It is not possible to state with any precision how much money is actually spent on speech and language rehabilitation and diagnosis. However, if we allow for a very modest 10 percent, the cost comes to $8.8 million dollars per year. It seems reasonable to expect that costs would be similar for patients whose aphasia results from tumors or from brain trauma. We have previously estimated that there are about 200,000 Americans with aphasia from these causes. This would increase the costs by $4.4 million and give us an estimated total of $13.2 million involved directly in the speech and language diagnosis, treatment, and rehabilitation of aphasic patients.

That the foregoing estimate is reasonable is suggested by information from the Veterans Administration. The VA provides speech and language rehabilitation services in many of its hospitals. The great majority of the case load is made up of aphasic patients. (Persons receiving training in esophageal speech following laryngectomy, and those with neuromotor disorders of speech related to such conditions as Parkinson's disease and multiple sclerosis make up the bulk of the remainder.) The VA currently employs 50 speech pathologists with an average salary of $12,000. This yields an annual cost of $600,000. In addition, direct services to patients are provided by graduate trainees in speech pathology. There are approximately 60 such trainees, and the average stipend for them is $4,000. The traineeship stipends thus amount to $240,000 yearly, bringing the total annual expenditure of the VA for professional personnel in speech and language to $840,000.

It must be pointed out that VA personnel have estimated that their present service program is reaching only one-fourth of the speech and language impaired population eligible for VA services in speech and language rehabilitation. In some centers, occupational therapists and educational therapists are attempting to do the work of the speech pathologist in addition to their own work. In other centers, no speech services are available at all. The situation is occasioned by current limitations on funds and on availability of adequately trained professional personnel. Thus, although the current annual cost for VA services in speech and language comes to only $840,000, the VA looks forward to an expansion of these services, which, if present costs hold, would increace the annual bill to over $3 million. There can be no question but that such an additional expenditure would be balanced many times over by the increase in the economic productivity of the speech and language impaired persons who would profit from the services.

A final consideration related to the costs of speech and language disorders to the nation is the question of the money involved in educating and training professional personnel.

According to the 1968 budget hearings cited earlier, Federal expenditures for training personnel to work with speech and language problems totaled better than $6,000,000 in Fiscal Year 1967. The clearly identifiable expenditures were $2,619,000 by the Office of Education, $766,000 by the Neurological and Sensory Disease Control Program and

$2,633,600[1] by the Vocational Rehabilitation Administration. In addition, the Children's Bureau supplied some training funds. Obviously, since all persons preparing to work with speech and language problems were not supported via the funding just mentioned and various kinds of institutional expenses are not accounted for, the total educational cost was probably double the amount we have here identified.

To summarize, we have seen that the annual cost of providing speech and language training to our handicapped school children comes to $70 million. Speech and language rehabilitation in our adult aphasia population amounts to $13.2 million. And the educational costs for professional preparation comes to well over $6 million. When we consider this total of $89.2 million, we must recognize that we have not included costs for habilitation of pre-school children, for rehabilitation of adults with speech and language disorders other than aphasia, and for the facilities, supporting personnel, and equipment required by professional speech and language clinicians. It seems clear that the annual costs would greatly exceed $100 million if all the data were in.

2. Indirect Costs. The indirect costs of central communicative disorders and of speech disorders are largely those of reduced earning power. We do not feel that there is any good way of estimating the effect on future income of disorders that occur in childhood. Ideally, elimination of a child's speech defect prior to his entering the labor market will open the door for him to achieve his full economic potential insofar as it is influenced by his communicative capacity. The same should for practical purposes be true if the speech disorder is largely, but not completely, overcome. In such event, the child's future earning power will not be in jeopardy.

The situation is more complex where central communicative disorders are concerned, because the child's learning capacity may be sufficiently affected so that his potential in adulthood will be limited by his ineptness in acquiring knowledge during his formative years. We see no satisfactory way of putting a price tag on the way such effects will influence income.

On the other hand, the central communicative disorders and speech disorders arising in adulthood often have very obvious financial effects. The school teacher who suffers aphasia from a stroke, the salesman who undergoes a similar fate because of an automobile accident, or the grocer whose larynx must be removed because of cancer all find their livelihoods directly threatened because they have lost the capacity to communicate adequately on the job. They will usually have to stop working or seek substitute employment which will usually pay less. Our previous discussions allow us to postulate that there are about 600,000 such persons in the country. Assuming, to be sure that we are on the conservative side, that two-thirds of these persons are either retired or are able to recapture their previous communicative skill through rehabilitation, we are left with 200,000 whose earning power has been seriously impaired. Assuming further that their financial loss averages $2,500 per person, the total deficit comes to about $500,000,000.

3. Human Travail. We are all aware of the fact that impairments in central communicative function or in speech impose a heavy price by disturbing the adjustments and interactions of everyday life. This price is extracted in those realms of human value which can not be measured in dollars. We have already discussed such intangibles during our consideration of hearing disorders. Hence, suffice it here merely to call attention once again to the paramount humanitarian importance of these intangibles.

C. *Summary on Costs of Communicative Disorders.* We can not say exactly how much communicative disorders are currently costing the Nation. Definitive data are almost wholly lacking. Nonetheless, we have drawn together what to us appears to be a reasonable and parsimonious cataloguing of most of the major items. One noteworthy feature of this discussion is that much more information is available on the expense of hearing impairments than on the expense of central communicative disorders or of speech disorders. This fact has made it possible to tabulate more of the costs of hearing disorders. Had similar information been available for the other two types of disorders, the costs we have assigned to them would undoubtedly have been markedly increased. However, even restricting ourselves to the amounts of our present estimate, the following three generalizations are possible.

1. The direct costs of coping with communicative disorders (special education, vocational rehabilitation, hearing aids, speech therapy, training of professional personnel, etc.) totals at least $500,000,000.
2. The annual deficit in earning power among the communicatively impaired approximates $1,750,000,000.
3. No price tag can be assigned to the personal tragedies and social misunderstandings which communicative disorders impose on their possessors.

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[1] The Vocational Rehabilitation Administration expended a total of $3,267,000 for training personnel in the speech and hearing field. We have already counted 20% of this amount earlier in computing the training costs in the field of hearing.

IV. RESEARCH ON HUMAN COMMUNICATION AND ITS DISORDERS

Disorders of human communication can be fully understood only if the processes of normal communication are also understood. This situation exists because faulty function can be assessed fully, and then corrected, only if one knows what the proper function should be. Such being the case, the scientific investigation for which NINDS is responsible can not limit itself to study of only the disorders themselves. This investigation must also include research on any problem that can supply information clarifying the communicative mechanisms and behaviors of normal individuals. The NINDS program must hold the premise, as it has since its inception, that the mastering of deviant behavior is inextricably linked with the deciphering of non-deviant.

Bearing this philosophy in mind, one can obtain an overview of research on human communication and its disorders by blocking out major categories that are encompassed by the NINDS responsibility. One of the Subcommittee's first tasks, therefore, was to attempt to develop a model depicting the key problem-areas and the approaches to them. The Subcommittee quickly discovered that no representation is really adequate. The areas to be encompassed have so many ramifications that no single model can encompass them to the satisfaction of all experts on communication. Nonetheless, the Subcommittee found that the diagram shown in Figure 2-2 proved a useful device envisioning the general areas of concern that are involved. Hence a quick explanation of this diagram is appropriate.

The model is depicted as a cube. Each of its three dimensions represents a different way of subdividing research.

The dimension labeled "Function" indicates that the problems can be catalogued into two groups, i.e., those dealing with normal operation of the communicative system and those dealing with its abnormal, or deviant, operation. These latter problems might result from disease, structural aberration, physiological peculiarity or faulty learning.

A second method of classification is indicated by the "Approach" dimension. One set of research questions in this dimension involves inquiry into the nature of communicative processes. Here one finds the questions dealing with the underlying theory and the basic science of communication rather than with the peculiarities of the individual communicator. Another set of questions is concerned with the identification and description of the behavioral entities, whether normal or abnormal, found in a particular human being. Such research falls more into the realm of clinical diagnosis. Finally, there are those questions involving methods of management. Here we are in the area of research on applied problems, i.e., research of the therapeutic and pedagogical varieties.

The third dimension is labeled "Communication Sequence." Here the five categories depict the location of phenomenon within the progression of onflowing events that comprise human communication. The first three categories deal with events occurring within the communicator. First, there are the mechanisms and the processes of reception (hearing). The second segment is concerned with central communicative activities, and the third with the functions that produce speech (effector segment). The fourth category involves phenomena that are essential to the individual's performance as a communicator but that occur outside the individual, i.e., are present in the media between individuals. Thus, for example, study of the acoustic composition of speech sound travelling through air helps us understand the nature of the stimulation acting on the ear and thus clarifies aspects of what makes speech intelligible. The last division of the "communicative sequence" is designated as "Phycho-social Relations." Here we find those questions which require investigation of the effect which interactions among people have on individual communicative behavior. We enter this area when we are interested in such topics as "What effect has parental treatment of a child on his linguistic maturation?" or "What, if any, is the role of social disapproval in inducing stuttering?"

The foregoing method of subdivision produces a set of classifications within which research problems can be organized. For example, studies designed to determine the role of normal inter-hemispheric interaction on understanding speech are classifiable as studies of (1) normal function that are (2) searching into the nature of processes in (3) the central segment of the communicative sequence. Likewise, research on the treatment of speech defects due to cleft palate is definable as investigation on (1) methods of managing (2) abnormal functioning within (3) the speech segment of the communicative sequence. Of course, many types of problems are encompassed within each sub-category depicted in the model, and even a broader variety is covered by the model as a whole. For example, topics range from electrophysiological investigations of the behavior of individual neurons to such questions as the role of multi-sensory stimulation in the rehabilitation of the adult aphasic. Or, as further examples, topics range from comparative studies of communication patterns in lower animal forms to investigations of the comparative merits of having two as opposed to one functioning ear.

As one would expect, many disciplines and subspecialties must be involved in the gathering and utilization of research data when such a wide

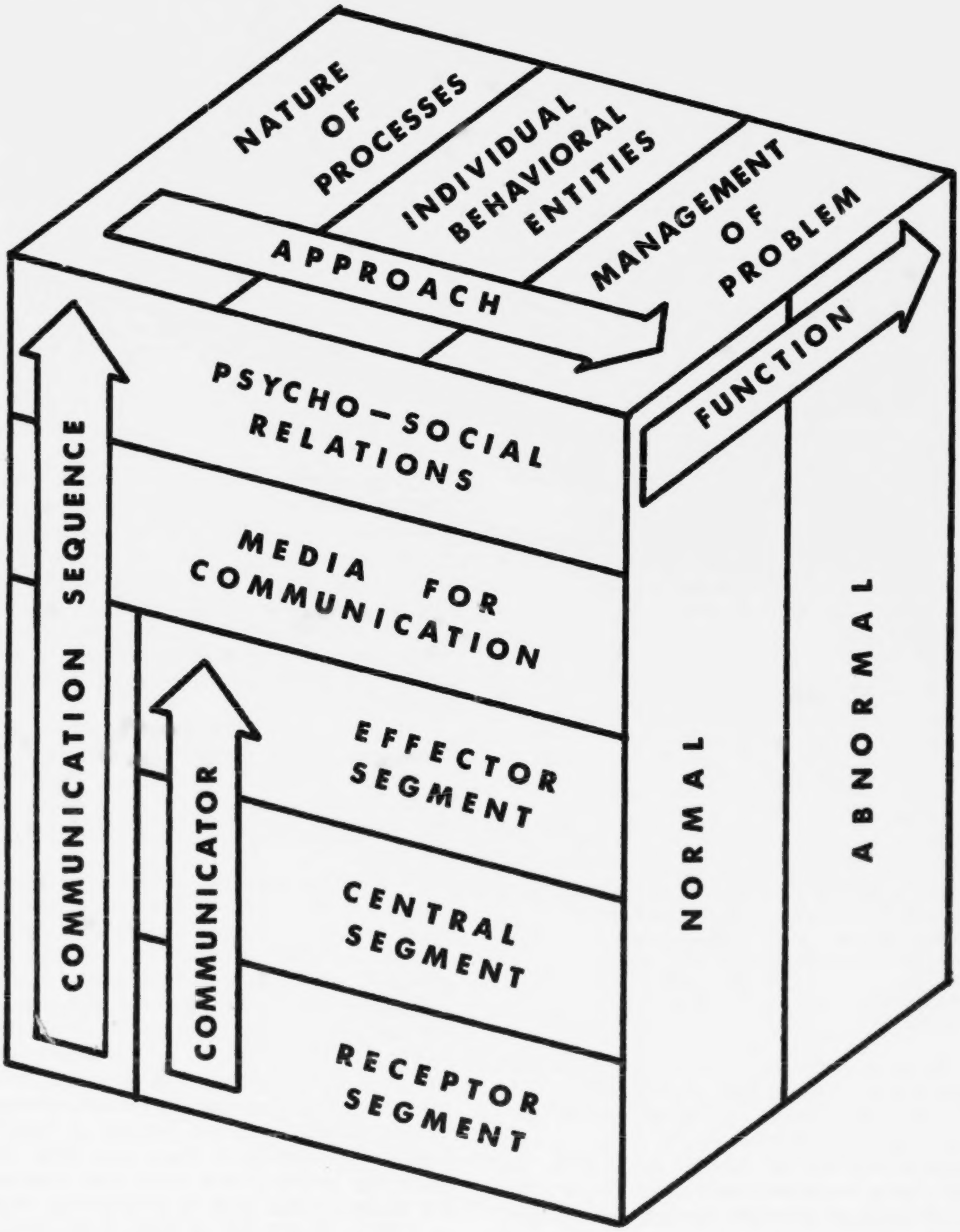
NATURE OF PROCESSES
INDIVIDUAL BEHAVIORAL ENTITIES
MANAGEMENT OF PROBLEM
APPROACH
FUNCTION
PSYCHO-SOCIAL RELATIONS
MEDIA FOR COMMUNICATION
EFFECTOR SEGMENT
CENTRAL SEGMENT
RECEPTOR SEGMENT
COMMUNICATION SEQUENCE
COMMUNICATOR
NORMAL
ABNORMAL

Figure 2-2. Model of the sequences, the functions and the approaches to the communicative process that help categorize the problem areas for research on human communication and its disorders.

diversity of topics and investigative emphases is encompassed. At one point in its work the Subcommittee accumulated a list of about 80 sub-specialties. Table 2-12 lists 50 professions which are among the more obviously linked to research on human communication and its disorders. The variety encompassed by even this partial listing is awesome.

The reader is requested to keep this diversity in mind as he evaluates the remainder of this report. However, it became apparent when the Subcommittee started writing the report that subsequent chapters could be most parsimoniously organized under the headings of Research on Hearing, Research on Central Communicative Processes and Research on Speech. Hence, topics involving either research on media for communication or on interpersonal relations have usually been incorporated within the foregoing headings as appropriate.

TABLE 2-12. Partial listing of specialists whose professions contribute importantly in research on human communication and its disorders.

Acoustic Engineer
Anatomist
Anthropologist
Audiologist
Bio-Acoustician
Bio-Chemist
Bio-Medical Engineer
Chlid Psychologist
Clinical Psychologist
Comparative Psychologist
Cryptographer
Educator of the Deaf
Electroencephalographer
Embryologist
Epidermologist
Ethnologist
Experimental Phonetician
Experimental Psychologist
Geneticist
Histologist
Information Theorist
Language Developmentalist
Laryngologist
Learning Theorist
Lexicographer
Neurologist
Neuropathologist
Neurosurgeon
Orthodontist
Otologist
Otoneurologist
Pediatrician
Pediatric Neurologist
Phonetician
Physiologist
Physiological Psychologist
Prosthodontist
Psychiatrist
Psychoacoustician
Psycholinguist
Psychometrist
Semanticist
Social Psychologist
Speech Developmentalist
Speech Pathologist
Speech Scientist
Structural Linguist
Statistician
Zoologist

The same simplification is found in the two sections which terminate the present chapter. The first of these two sections reviews our Nation's current support of research in the area of human communication that are of concern to NINDS. The second section summarizes current support for training of professional personnel to work in these areas.

V. Financial Support for Research

A. *Overall Support by NINDS of the Communicative Sciences.* During Fiscal Year 1968, the National Institute of Neurological Diseases and Stroke had 1,780 active extramural research grants funded in the amount of $65,147,000 (Director's Annual Report on Extramural Programs of the National Institute of Neurological Diseases and Blindness for July 1, 1967 through June 30, 1968, Appendix A). Almost 56 percent (55.6%) of this money was used to support research on neurological disorders, 24.5 percent for vision research, 13.6 percent for research in the communicative sciences, and the remainder on other sensory disorders and on non-categorical projects. The total award to communicative sciences was $8,847,000, with $6,894,-000 being allocated to hearing and equilibrium, and $1,863,000 to speech and other higher CNS functions. In terms of the individual research projects involved, there were 1,066 dealing with neurological disorders, 386 with vision, 217 with communicative science (of which 39 were devoted to speech production and central communication processes, while 178 dealt with hearing and equilibrium).

Concurrently, the total support for intramural research was $18,270,000. This sum was distributed as follows: $15,136,120 (82.8%) for neurological disease, $2,402,000 (13.2%) for vision, $403,000 (2.2%) on communicative disorders and $328,880 (1.8%) on other types of problems. Within the category of communicative disorders, expenditures for hearing and equilibrium were $295,000 as opposed to $108,000 for speech production and central communicative functions.

It is clear from the foregoing figures that the NINDS extramural program was more heavily committed to the communicative sciences (with 13.6% of 1968 expenditures in this area) than was its intramural program (with 2.2% of 1968 expenditures in this area).

NINDS support for research on human communication and its disorders has increased steadily during the past decade and has followed the pattern reported in Tables 2-13 and 2-14. This trend is to be expected in consequence of the general rise in appropriations which the Institute has experienced. One interesting feature (see Table 2-13) is that the proportion of NINDS research funds channeled into the communicative sciences has remained relatively constant at a little less than 10 percent, although this fraction jumped from 9.5 percent in Fiscal year 1966 to 11.1 percent in Fiscal year 1968. Another interesting feature is that actual sums expended on the communicative sciences jumped from $920,580 in 1958 to $9,250,000 in 1968. Concurrently, the number of projects increased from 58 to 228. Thus, a ten-fold increase in the available money was accompanied by less than a four-fold increase in research projects; the size of the average award rose from $15,872 to $40,570. Finally, as shown in Table 2-14, the intramural efforts remained only a fraction

TABLE 2-13. History of NINDS funding of research in human communication and its disorders since Fiscal Year 1958 (extramural and intramural programs combined).

(Derived from Director's Annual Report, 1968 and related tabulations)

		Awards in Communicative Science		
Fiscal Year	Total Expenditures for reserach	Amount	Per Cent of Total Expenditures	Number of Projects
1958	$ 9,700,000	$ 920,580	9.5	58
1959	15,200,000	1,357,055	8.9	82
1960	23,000,000	2,455,100	10.7	107
1961	36,336,000	2,306,583	6.4	120
1962	44,100,000	3,840,226	8.7	144
1963	49,696,000	4,836,495	9.8	174
1964	58,499,000	5,461,606	9.3	179
1965	61,989,000	5,645,000	9.1	186
1966	68,448,000	6,533,000	9.5	195
1967	77,421,000	8,178,000	10.6	216
1968	83,417,000	9,250,000	11.1	228

TABLE 2-14. History of NINDS funding of extramural research and of intramural research in human communication and its disorders since fiscal year 1958.

(Derived from Director's Annual Report, 1968 and related tabulations)

Fiscal	Extramural		Intramural		Total	
Year	Grants	Amount	Projects	Amount	No.	Amount
1958	53	$ 850,117	5	$ 70,463	58	$ 920,580
1959	74	1,108,996	8	248,059	82	1,357,055
1960	98	1,965,357	9	489,743	107	2,455,100
1961	112	2,168,083	8	138,500	120	2,306,583
1962	138	3,637,000	6	203,226	144	3,840,226
1963	164	4,334,495	10	502,000	174	4,836,495
1964	173	5,038,606	6	423,000	179	5,461,606
1965	171	5,208,000	15	437,000	186	5,645,000
1966	175	6,000,000	13	533,000	188	6,533,000
1967	197	7,637,000	13	541,000	210	8,178,000
1968	217	8,847,000	11	403,000	228	9,250,000

TABLE 2-15. Amounts of NINDS support during recent years for research on hearing and equilibrium as contrasted to other facets of communicative science; plus proportions of the total allocation for communicative science represented by these amounts.

(Based on Director's Annual Report, 1968 and related tabulations)

	Extramural		Intramural	
Fiscal Year	Hearing	Other	Hearing	Other
1966—				
Amount	$4,499,000	$1,501,000	$383,000	$150,000
Per Cent	75%	25%	72%	28%
1967—				
Amount	5,971,000	1,666,000	389,000	152,000
Per Cent	78%	22%	72%	28%
1968—				
Amount	6,984,000	1,863,000	295,000	108,000
Per Cent	79%	21%	73%	27%

TABLE 2-16. Distribution of NINDS Research Grants by communicative category for Fiscal Year 1968 and approximate amounts expended according to research areas as categorized by the Subcommittee.

(Based on Fiscal Year 1968, *Research Summary Book*)

Major Communicative	Grants		Funding	
Category	No.	%	Amount	%
Hearing processes and their impairments	169	78.2	$6,492,377	72.0
Central processes and their impairments	19	8.8	1,090,490	12.1
Speech processes and their impairments	24	11.1	1,262,610	14.0
Other: i.e., Cutaneous communications, etc.	4	1.9	167,111	1.9
TOTAL	216	100.0	$9,020,688	100.0

of the extramural effort in this area (both in budget and in number of projects).

Table 2-15 emphasizes a significant fact which has already been mentioned: namely, that support of hearing and equilibrium is currently greater than support of other facets of communicative science. The proportions from Fiscal Year 1966 through Fiscal Year 1968 were 79 percent to 21 percent for extramural research and 73 percent to 27 percent for intramural research.

A further analysis of extramural research for 1968 was from the Summary Book on Research Grants, Fiscal Year 1968, compiled by the Institute. Table 2-16 summarizes the outcome. The totals, both of active projects and of funds expended, differ slightly from those given earlier because the Subcommittee felt justified in shifting the classification of a few research projects and because the time span under consideration was slightly different than in the compilation discussed earlier; but the fact that hearing absorbed about three quarters of NINDS support in communicative sciences is confirmed. Interestingly, speech received 11% of the projects (24 grants) and 14% of the funds ($1,262,610); while central communicative processes garnered only about 9% of the projects (19 grants) and 12% of the funds ($1,090,490). Finally, there were 4 grants ($167,111) for miscellaneous related research.

Keeping the foregoing general analysis in mind, the next task becomes one of examining in which sub-areas of communicative science NINDS has supported research.

1. Support for Research on Hearing. Tables 2-17 and 2-18 present two pictures of the distribution within the hearing field of NINDS supported projects. Table 2-17 presents the distribution according to the aforementioned analysis performed by the Subcommittee, and Table 2-18 according to the classification scheme used by NINDS.

TABLE 2-17. Distribution of NINDS extramural research grants in hearing and approximate amounts expended in Fiscal Year 1968 according to research areas as categorized by the Subcommittee.

(Based on Fiscal Year 1968, *Research Summary Book*)

	Grants		Funding	
	No.	%	Amount	%
NON-CLINICAL				
Basic anatomy and physiology	28	16.6	$891,036	13.7
Normal psychoacoustics	20	11.8	873,157	13.4
Animal: Electrophysiology	32	18.9	1,117,257	17.2
Animal: Other Experimentation	18	10.7	586,610	9.1
CLINICAL				
Audiological	22	13.0	1,024,720	15.8
Ear Diseases: Temporal bone	12	7.1	325,796	5.0
Ear Diseases: Other	8	4.7	197,516	3.1
Vestibular (incl. Meniere's)	24	14.2	1,021,715	15.7
Deaf and their management	5	3.0	454,570	7.0
Management of hard of hrg.	0	0.0	....	0.0
TOTAL	169	100.0	$6,492,377	100.0

TABLE 2-18. Distribution of extramural research grants in hearing and amounts expended in Fiscal Year 1968 according to major categories as classified by NINDS.

	Grants		Funding	
Category	No.	%	Amounts	%
Deafness and hearing loss	53	31.4	$1,740,966	26.8
Inner ear and cochlea	45	26.6	1,504,369	23.3
Electrophysiology and anatomy of auditory system	12	7.1	378,495	5.8
Hearing discrimination	28	16.6	957,316	14.7
Middle ear, otosclerosis, otitis, equilibrium loss	8	4.7	209,583	3.2
Vestibular system	13	7.7	348,621	5.4
Program Projects including four Temporal Bone Banks	10	5.9	1,353,027	20.8
TOTAL	169	100.0	$6,492,377	100.0

TABLE 2-19. Distribution by research categories of intramural research projects on hearing conducted by NINDS in Fiscal Year 1968.

Category	Number of Projects
Neuroanatomy	4
Electrophysiology	1
Information Center—Human Communication (Hearing and Speech)	1
Middle Ear Disease	1
Aid for the Deaf	1
Preschool Screening	1
TOTAL	9

Table 2-17 reveals that 58 percent of these projects (98) were concerned with non-clinical topics: with basic anatomy and physiology, with normal psychoacoustics and with animal experimentation. These 98 projects received 53 percent of the financial support for hearing research. A fact of considerable interest is that almost a third (32) of these 98 studies were in the area of experimental electrophysiology (cochlear microphonics, action potentials, single unit response, etc.) and another quarter (18) on other types of animal experimentation (ranging from effects of drugs on the inner ear to behavioral works). Thus, half of these 98 studies employed animals. By contrast, less than a quarter (20) of the 98 projects were concerned with the normal processes of human audition. The remainder (28) were in basic areas ranging from comparative anatomy and biochemistry to neuroanatomy and processes of bone growth.

The other 42 percent (71) of the investigations were clinical, but their distribution was uneven. Almost a third (22) of these dealt with audiological topics (ranging from development of testing tools to audiological procedures in differential diagnosis), seventeen percent (12) focused on the subtleties of ear disease as these subtleties are revealed by postmortem dissection and/or sectioning of human temporal bones; while about a ninth (8) were directed toward other aspects of ear disease (including both middle and inner ear disease). Lastly, only 5 projects dealt with either education or rehabilitative management of persons with hearing impairment, and all 5 were studies on the deaf. Research on post-surgical and/or post-medical management of the partially impaired is notable for its absence.

The picture presented by Table 2-18 is also interesting. Here the most notable features are (1) the dearth of research on conductive hearing loss and (2) the fact that there were 10 program projects (if one so classifies four Temporal Bone Bank endeavors). These 10 projects consumed approximately 21% ($1,353,027) of the funds spent in 1968 on research in hearing.

As regards intramural research, the studies on hearing supported by NINDS are shown in Table 2-19. Here the heavy emphasis has clearly been on neuroanatomy.

2. Support of Research on Central Communicative Processes. As can be seen from Table 2-20, 13 of the 19 extramural research grants supported during 1968 in this area were non-clinical, dealing either with normal CNS functions or employing surgically altered animals. The remaining 6 projects were clinical, with more emphasis being given to problems of adults than to problems of children. The proportions of funds expended roughly parallels the foregoing distribution.

TABLE 2-20. Distribution of NINDS extramural research grants in central communicative processes and approximate amounts expended in Fiscal Year 1968, according to research areas as categorized by the Subcommittee.

(Based on Fiscal Year 1968, *Research Summary Book*)

	Grants		Funding	
	Number	%	Amount	%
CNS Functions	10	52.6	$495,964	45.5
Animal Experimentation	3	15.7	151,785	13.8
Central Damage: Children	1	5.3	121,948	11.2
Central Damage: Adults and all ages	4	21.1	288,518	26.5
Temporal Lobe Pathology	1	5.3	32,275	3.0
TOTAL	19	100.0	$1,090,490	100.0

3. Support of Research on Speech Processes. Table 2-21 gives the breakdown by research areas for NINDS's extramural projects for 1968 dealing with speech. Almost three fifths (14) were concerned with basic processes or normal function. Another fifth (5) attacked clinical topics, while the last fifth (5) dealt with relatively general aspects of the field (including one program project) but may also be constructed as clinical in focus. The distribution of expenditures did not parallel too closely the proportions of grants in the several areas involved. However, the discrepancy is not unexpected when one remembers that a major fraction of the total expenditure was for a research program project catalogued as general in scope.

4. Support of Other Research. As reported earlier, there were 4 grants ($167,111) for studies involving facets of human communication not classifiable in categories already mentioned. In addition, strong recognition must be given to the fact that NINDS's Perinatal Project, while not conceived as having communicative processes as its primary focus, includes periodic analysis of hearing, speech and central capacities. Thus, this monumental undertaking is accumulating an invaluable store of sequential information on critical aspects of the communicative process. Moreover, a few special research projects (included in earlier tabulations) on hearing and speech are underway which take advantage of the pool of children (and the copious data on them) made available by the Perinatal Project.

B. *Overall Support of the Communicative Sciences by Other Federal Agencies.* Information on the Federal support of research on human communication and its disorders other than by NINDS is elusive because so many agencies with such diverse missions are involved. There is no central source of fully inclusive and well-coordinated records to which one can turn. Nonetheless, some idea of the magnitudes and concentrations of this research are obtainable.

TABLE 2-21. Distribution of NINDS extramural research grants in speech and approximate amounts expended in Fiscal Year 1968, according to research areas as categorized by the Subcommittee.

(Based on 1968, *Research Summary Book*)

	Grants		Funding	
	No.	%	Amount	%
General Physiology and Acoustics	6	25.0	$324,999	25.7
Laryngeal Physiology	8	33.3	347,612	27.5
Laryngeal Dysfunction	3	12.6	74,673	5.9
Other Speech Disorders	2	8.3	80,957	6.4
General	5	20.8	434,369	34.5
TOTAL	24	100.0	$1,262,610	100.0

An estimate of the research supported by segments of the Department of Health, Education and Welfare other than the National Institutes of Health can be obtained from the 1967 Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, 89th Congress, Second Session. The Office of Vocational Rehabilitation requested $1,280,000 to Support 31 research and demonstration projects on communicative problems, with 18 of these projects being concerned with having disorders and 13 with central or speech disturbances. The Office of Education concurrently requested continued support for about 25 demonstrations, cooperative and educational media research projects, but exact details are not included in the statement submitted to the Committee on Appropriations. Lastly, the Children's Bureau funded a limited number of projects, the expected cost of which likewise was not specified. Summarizing, the agencies mentioned supported a sizeable number of research activities, in an amount probably not exceeding $2,000,000, which focused on communicative problems. It should be mentioned that these endeavors were primarily extramural and stressed investigation of practical problems.

A somewhat broader, although still not fully satisfactory, view of the scope of federally supported research on speech and hearing can be abstracted from a compilation, made in 1965 for our Subcommittee, of all active and pertinent research projects then on record with the Science Information Exchange of the Smithsonian Institution. True, this compilation is incomplete because not all active projects were listed with this exchange. This lapse is particularly marked for projects receiving private or local support, but it is also true of some receiving Federal support. Moreover, it was not possible for us to arrive at a firm figure regarding the costs of the research involved because the time spans for various projects varied. Nonetheless, the data on distribution of projects among agencies and among research topics are most instructive. These data are assembled in Table 2-22. Note from Part A of the table that a total of 471 projects in the field of human communication and its disorders were on record in 1965 at the Science Information Exchange. All but 34 (7.2%) of these were funded by the Federal Government. NINDS supported 154 (32.7%) of the total and the other National Institutes of Health supported an additional 85 (18.1%). Thus, *in toto*, NIH sponsored 239 (50.8%) of all projects reported. Other subdivisions of the Department of Health, Education and Welfare funded 61 (12.9%) additional endeavors, bringing the aggregate for DHEW to 300 (63.7%) of all projects. The Armed Forces sponsored 49 (10.4%), Veterans Administration 48 (10.2%) and other agencies 40 (8.5%) of the total. All told, then, 437 (92.8%) projects operated with Federal funds.

The foregoing figures are deceptive in two regards. First, some topics that are pertinent tend often to be classified under headings which would have militated against their inclusion in this foregoing listing. For example, some communicative science research is undoubtedly listed under experimental psychology. Second, as already mentioned, many studies never get listed with the Science Information Exchange. These two limitations result in somewhat false pictures of the proportions of research emphasis, and they yield a spuriously low overall total. However, two conclusions are still possible. First, a substantial amount of research is being carried on in the communicative sciences. Second, the Federal government is subsidizing a very large fraction of this research.

Turning to the question of the distribution of the aforementioned projects within the major areas of communicative science, one notes in Table 2-22 (see parts A and C of the Table) that 254 (53.9%) projects were devoted to hearing, 115 (24.4%) to central communicative processes, 73 (15.5%) to speech and the remaining 29 (6.2%) to topics not falling sharply into one of the foregoing three categories. One also notes (See Part C of the Table) that proportional emphasis differed widely from agency to agency. Projects on hearing constituted about 70 percent of the aggregate supported by NINDS and by the Armed Forces, but only 23.5 percent of the projects supported by Institutes of Health other than NINDS. Other segments of DHEW, Veterans Administration and non-Federal sources sponsored hearing projects 50.8, 56.2 and 58.8 per cent of the time, respectively. Conversely, central processes received their greatest support from NIH Institutes other than NINDS (36.5%), from non-Federal sources (32.4%), from Veterans Administration (29.2%) and from segments of DHEW other than NIH (26.2%). NINDS (11.7%) and the Armed Forces (12.2%) were particularly low in

TABLE 2-22. Distribution of research projects on human communication and its disorders: 1965 data from Science Information Exchange.

Part A: Number of Projects

	DEPT. HEW			OTHER FEDERAL				
Major Categories	NINDS	OTHER NIH	OTHER HEW	ARMED FORCES	VETERANS ADM.	OTHER AGENCIES	NON-FEDERAL	TOTAL
Hearing Processes and Disorders	110	20	31	34	27	12	20	254
Central Processes and Disorders	18	31	16	6	14	19	11	115
Speech Processes and Disorders	23	26	5	9	4	4	2	73
Other	3	8	9	0	3	5	1	29
TOTALS	154	85	61	49	48	40		
			300			137		
						437	34	
								471

TABLE 2-22. (continued) Distribution of research projects on human communication and its disorders: 1965 data from Science Information Exchange.

Part B: Percentage by Agency

	DEPT. HEW			OTHER FEDERAL				
Major Categories	NINDS	OTHER NIH	OTHER HEW	ARMED FORCES	VETERANS ADM.	OTHER AGENCIES	NON-FEDERAL	TOTAL
Hearing Processes and Disorders	43.3	7.9	12.2	13.41	10.6	4.7	7.9	100
Central Processes and Disorders	15.6	27.0	13.9	5.2	12.2	16.5	9.6	100
Speech Processes and Disorders	31.5	35.6	6.8	12.3	5.5	5.5	2.7	100
Other	10.3	27.6	31.0	0.0	10.3	17.2	3.5	100
Combined Percent	32.7	18.1	12.9	10.4	10.2	8.5		
			63.7			29.1		
						92.8	7.2	
								100

TABLE 2-22. (continued) Distribution of research projects on human communication and its disorders: 1965 data from Science Information Exchange.

Part C: Percentage by Research Category

	DEPT. HEW			OTHER FEDERAL				
Major Categories	NINDS	OTHER NIH	OTHER HEW	ARMED FORCES	VETERANS ADM.	OTHER AGENCIES	NON-FEDERAL	TOTAL
Hearing Processes and Disorders	71.4	23.5	50.8	69.4	56.2	30.0	58.8	53.9
Central Processes and Disorders	11.7	36.5	26.2	12.2	29.2	47.5	32.4	24.4
Speech Processes and Disorders	14.9	30.6	8.2	18.4	8.3	10.0	5.9	15.5
Other	2.0	9.4	14.8	0.0	6.3	12.5	2.9	6.2
Total	100	100	100	100	100	100	100	100

this area. Speech processes received scantier overall support. They constitute 30.6 per cent of grants in communicative science by NIH Institutes other than NINDS. Only NINDS (14.9%) and the Armed Forces (18.4%), among the other agencies, had more than 10 per cent of their projects allocated to speech.

Table 2-23 re-summarizes the 1965 data furnished by the Science Information Exchange according to our classification of sub-categories within the field of communicative science. The following sections analyze the outcome.

1. Support for Research in Hearing. It can be seen in Table 2-23 that a total of 222 projects which were listed in 1965 with the Science Information Exchange dealt with aspects of hearing and hearing impairments (exclusive of problems in deafness). Seventy-two of these 222 projects were concerned with basic studies, 50 with audiological topics, 53 with otolaryngological ones, 37 with problems of the vestibular system and only 10 with the questions of rehabilitation. Distributions according to these subdivisions are fairly uniform from one agency to another except that (1) NINDS and the Armed Forces were heavier in emphasis on basic problems and studies of vestibular mechanisms, (2) NINDS and Veterans Administration had strong concentration in the audiological realm; (3) NINDS, other Institutes of NIH and non-Federal sources all gave good support to otolaryngological problems, while (4) Veterans Administration supported 7 of the 10 rehabilitation projects.

An additional 32 projects were devoted to the problems of the deaf and their management. Fourteen of these explored the skills and abilities of the deaf, while the other 18 focused on the training and the social interactions of such persons. Moreover, all but one of the 32 projects was sponsored from within the Department of Health, Education, and Welfare (with 18 projects under the aegis of the Rehabilitation Services Administration).

2. Support for Research on Central Communicative Processes. Projects dealing with central communicative processes are catalogued not only under the heading of central communicative processes itself but also under the heading of language. (See Table 2-23) A total of 79 projects was assignable to the first of these two categories. Thirty-four of these 79 dealt with the basic nature of central processes, 30 more with the nature of disorders in the central processes and the final 15 with the management of central disorders. The various divisions of the Department of Health, Education, and Welfare supported 51 of the 79 projects. Veterans Administration was also relatively active, conducting 13 projects. It should be noted that the 79 projects were distributed in such manner that the primary emphasis of the National Institutes of Health (including NINDS) was more on basic problems, with other segments of DHEW giving proportionately more support to clinical topics.

An additional 36 investigations dealing with language were reported by the Science Information Exchange. In view of the tremendous contemporary interest in linguistics, one can not assume that these 36 studies represent more than a small part of the research in linguistics going on in this country. Nonetheless, these 36 studies reveal several interesting trends. For example, not one of the projects sponsored by NINDS falls in this category, but 13 of the 85 projects sponsored by other Institutes of NIH do. Again, support for 16 projects was derived from other Federal agencies. Almost all of these latter were studies in basic or comparative linguistics funded through the National Science Foundation.

In summary, NINDS had a relatively small proportion of grants in the area of central communicative process, other Institutes of NIH had a higher proportion, and substantial support (particularly in the realms of disordered central processes and in linguistics) came from outside DHEW.

3. Support of Research on Speech. Only 73 projects on speech processes and their impairments were included in the 471 reported to us in 1965 by Scientific Information Exchange (See Table 2-23). The 73 projects were almost evenly divided between studies on basic problems and investigations on speech disorders. Moreover, the preponderance of the 73 were funded through NIH, 23 via NINDS and 26 via other Institutes. Studies on basic speech processes were in the majority among those supported by NINDS, while research on speech disorders predominated for the other NIH Institutes. The Armed Forces contributed 9 projects, all in the basic area, but support from other agencies outside the Department of Health, Education and Welfare was very skimpy.

4. Support of Miscellaneous Research. Table 23 includes 29 projects that were miscellaneous. Fourteen of these dealt with general problems in the speech and hearing field. The remaining 15 included 4 concerned with the media for communication and 11 with its inter-personal aspects. However, these last two tabulations must be considered grossly incomplete. For example, no information was available to us on the many investigations of speech and hearing performed in the field of acoustics, and we had only scant information on research in psychiatry and sociology that involves communicative interaction.

C. *Support of Research in Communicative Sciences from Non-Federal Sources.* Nothing approaching comprehensive statistics is available concerning the amount of money which non-Federal agencies contribute to research in human communication and

TABLE 2-23. Distribution by sub-category of research on human communication and its disorders: 1965 data from Science Information Exchange.

	DEPT. HEW			OTHER FEDERAL				
	NINDS	OTHER NIH	OTHER HEW	ARMED FORCES	VETERANS ADM.	OTHER AGENCIES	NON-FEDERAL	TOTAL
Hearing and Hearing Impairment								
Basic	39	4	1	18	0	8	2	72
Audiological	30	3	1	3	10	0	3	50
Otolaryngology	26	8	2	1	5	0	11	53
Vestibular	13	0	0	12	5	3	4	37
Rehabilitation	0	0	3	0	7	0	0	10
Total	108	15	7	34	27	11	20	222
Deaf and Their Management								
Skills & Ability	2	4	8	0	0	0	0	14
Training & Social Interaction	0	1	16	0	0	1	0	18
Total	2	5	24	0	0	1	0	32
Central Communicative Processes								
Basic	9	11	5	4	0	2	3	34
Nature of Disorders	4	6	6	0	9	0	5	30
Management of Disorders	5	1	4	0	4	0	1	15
Total	18	18	15	4	13	2	9	79
Language								
Nature of Lang.	0	8	0	0	1	16	1	26
Communicative Features	0	5	1	2	0	1	1	10
Total	0	13	1	2	1	17	2	36
Speech								
Basic	13	8	1	9	1	4	0	36
Speech Disorders	10	18	4	0	3	0	2	37
Total	23	26	5	9	4	4	2	73
Communicative Processes								
General Speech and Hearing	3	4	6	0	0	0	1	14
Media	0	0	2	0	0	2	0	4
Interpersonal Aspects	0	4	1	0	3	3	0	11
Total	3	8	9	0	3	5	1	29
Grand Total	154	85	61	49	48	40		
	300			137				
	437						34	
								471

its disorders. Therefore the present remarks must be limited to two general statements, one dealing with voluntary health agencies and the other with the role of universities.

Voluntary agencies in the field of communicative disorders are of two types, those that are professional associations and those whose purpose is to conduct fund-raising drives with which to offer clinical services to the public or with which to support mission-oriented research. Professional associations such as the American Speech and Hearing Association lack the capital to initiate large independent research endeavors with their own funds. However, such an association often serves as the vehicle through which outside money, often from the Federal Government, can be channeled into special research projects which are best conducted by that national organization. A notable example has been the extensive investigation of damage to hearing by industrial noise which the Subcommittee on Noise of the American Academy of Ophthalmology and Otolaryngology has sponsored during the past dozen years. This investigation was supported in substantial measure by insurance companies.

Voluntary fund-raising agencies in the field of communicative disorders have given important support to research, although the dollar volume has not been too large. The situation is illustrated by considering briefly the roles of three major agencies of this type. These agencies are the United Cerebral Palsy Association, The Deafness Research Foundation and the National Society for Crippled Children and Adults.

The United Cerebral Palsy Association spent a total of $862,566 in 1966 on research and training grants. This organization has a scope of interest which embraces much more than only the communicative disorders associated with cerebral palsy. One can thus understand the fact that only $27,036 of the sum mentioned above was allocated to studies focusing on communication. There were three such studies. One of these was a general investigation of communicative disorders, another was in the area of audition and the third dealt with language.

The Deafness Research Foundation is a relatively young organization with limited funds. It has adopted a general policy of making research awards, primarily in otology, to promising investigators. These awards, usually in the range of $6,000 to $8,000, are renewable for a total of three years. It is hoped that after this period of support, a productive investigator will be able to attract support for continued research from Federal agencies. In the eleven years that the Deafness Research Foundation has been in operation, the total amount awarded has been over $2,500,000. These grants have been made to investigators in 50 institutions. Moreover, much of this support has been for encouragement and refinement of a nationwide network of temporal bone laboratories.

The scope of the Easter Seal Research Foundation program, which is a function of the National Society of Crippled Children and Adults, includes support of research in all aspects of communication and communicative disorders. Particular emphasis is on children with special learning disabilities due to minimal cerebral dysfunction. Since 1956 when this grant program was initiated, there have been 13 grants in the field of communication totalling $257,044.

Universities have been the foremost non-Federal organizations contributing to research in communicative disorders. True, the support which comes from their own coffers tends to be disregarded because universities are also the primary outlets through which Federal grants and contracts in this area are expended. However, substantial academic programs in communicative science and communicative disorders were in existence before the present scope of Federal support for research evolved. These academic programs were achieved through funding by the universities themselves of faculty salaries, laboratory facilities and student assistantships. This type of funding is budgetarily obscure, and we shall not try to estimate it here. However, such hidden funding can not help but continue to total a large amount. One way of estimating its impact is to look briefly at the amount of research done by graduate students. Such investigation goes on all the time, and its full scope at any given point in the academic calendar is hard to define. However, some idea can be obtained by looking at the number of graduate theses completed in the field of communicative disorders. In 1955, there were 167 graduate theses accepted in this field (Knower, F. H., Graduate Theses in Speech and Hearing Disorders, *Journal of Speech and Hearing Disorders*, 22 (1957) 104-112). One hundred thirteen of these were masters' theses and 54 were Ph.D. dissertations. This was a sizeable group, but by 1967 the total had risen to 256 theses: 175[1] at the masters' level and 81 at the doctoral level. (Knower, F. H., Graduate Theses: An Index of Graduate Research in Speech and Cognate Fields, *Speech Monographs*, 35 (1968) 348-399). Apparently, Knower's data does not include all doctoral degrees in the fields of speech pathology and audiology. The American Speech and Hearing Association conducted a survey which indicates that 36 schools granted 105 doctorates in these fields during 1967 and 46 institutions granted 129 such degrees in 1968. (Fricke, J. E., The Status of Education and Training Programs for Speech Pathology and Audiology, ASHA, 11, 1969, in press). The important point is that dissertation research is certainly one of the major sources of increasing knowledge of human communication and its disorders. We recognize that the recent increase is at least partly due to Federal grants in the form of graduate traineeships and fellowships, along with specific research grants. Here, however, we are stressing the fact that our universities typically do contribute substantially to such research even when Federal assistance is involved. Moreover, in a great many instances, the cost of student support, faculty direction, and research equipment is borne mainly or exclusively by the university. We must also recognize the universities' contribution in terms of the time and facilities made available directly to faculty members for their own research. We would do our academic institutions great injustice if we were to accept the view that research on human communication and its disorders at these instititutions is the outgrowth of our recent growth in Federal support for science. Federal funds have greatly enhanced and strengthened investigation in these areas, but the commitment to foster such research had been made by many administrators and faculty members when extra-institutional funding was still in short supply.

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[1] The increase in M.A. theses is less than one would expect until one remembers that the trend in M.A. programs has been away from maintaining the thesis as a degree requirement. Actually, 1210 masters degrees in speech pathology and audiology were granted in 1967 and 1567 were granted in 1968 (Fricke, *op. cit.*)

4. Summary on Support for Research. Tabulations available to us on research dealing with human communication and its disorders indicates that NINDS, other Institutes within NIH, and other segments of HEW supply the lion's share of all funding for such research. And, were it not for this situation, the field of communicative sciences would be largely neglected as an arena for vigorous research. A little more than one-tenth of the NINDS research effort is so directed, with expenditures now exceeding eight million dollars annually. Viewed in broader context, NINDS supported about one-third of the projects listed with the Science Information Exchange in 1965. The remaining Institutes sponsored another sixth of the total while other agencies within HEW funded still an additional sixth. Almost all of the last third of the projects are under the aegis of Federal agencies outside DHEW, notably the Armed Forces and Veterans Administration. It is startling that a scant 7 percent of the projects known to the Science Information Service were not budgeted through Federal channels.

Another set of facts of significance is that research on hearing processes predominates over research on central communication processes or on speech processes. The former comprises almost 80 percent of the NINDS commitment within the communicative sciences and better than half of the projects listed by the Science Information Exchange. Research projects on central communicative processes are rare in the roster of NINDS support but blossom to about a fourth of the total when the efforts of other agencies are taken into account. By contrast, investigations of speech processes comprise about one seventh of the total by either criterion.

Lastly, however, private agencies and the academic community also support important research on human communication and its disorders. The dollar expenditure here is impossible to ascertain, primarily because the direct expenditure by universities for such research does not appear as a set of identifiable budgetary items. We may be sure, however, that this expenditure is sizeable.

VI. FINANCIAL SUPPORT FOR TRAINING OF INVESTIGATORS

A. *Support from NINDS*. The Institute maintains training grants, fellowships and career development awards which form an important part of its attack on communicative disorders. As of Fiscal Year 1968, NINDS sponsored 67 training grant programs in otolaryngology, audiology, speech pathology and sensory physiology. There were 299 post-doctoral students in these programs. In addition, 2 developmental training grants in otolaryngology were in effect, plus 13 Career Development Awards and 2 Career Awards in the communicative sciences. The focus of all the foregoing awards is to recruit and train laboratory and clinical scientists for careers in research and research training. The distributions of emphasis in these various activities are summarized in Tables 2-24 through 2-27. These tables are derived primarily from the Director's Annual Reports on Extramural Programs of the National Institute of Neurological Diseases and Blindness for July 1, 1967 through June 30, 1968.

1. Training Grants. Table 2-24 reveals that 69 (22.3%) of all training grants active via NINDB in Fiscal Year 1968 were allocated to the field of human communication and its disorders. These grants received $3,767,000, which is 23.2 percent of the Institute's expenditures for training. The foregoing figures indicate that the Institute gives proportionately greater support to training in the communicative field than to research in this area, which it will be recalled, received 10.5 percent of the Institute's allocation for extramural research.

Table 2-25 summarizes the distribution within the communicative sciences of the aforementioned 69 training grants. Fifty (72.6%) of these grants were in otolaryngology, with $2,605,000 (68.2%) being spent for them. Thirteen (18.8%) grants fo-

TABLE 2-24. Distribution of Training Grants supported by NINDS in Fiscal Year 1968, showing allocation to the various areas of human communication and its disorders.
(Derived from Director's Annual Report, 1968)

Field of Training	Grant		Funding	
	No.	%	No.	%
1. All except communicative science	237	77.5	$12,531,000	76.9
2. Communicative Science				
Communicative Disorders	3	1.0	222,000	1.4
Medical Audiology	7	2.3	357,000	2.2
Otolaryngology	49	16.0	2,486,000	15.2
Otolaryngology and Audiology	4	1.3	266,000	1.6
Otolaryngologic Pathology	1	0.3	119,000	0.7
Speech Pathology	2	0.6	93,000	0.6
Speech Pathology-Audiology	3	1.0	224,000	1.4
Subtotal	69	22.5	3,767,000	23.1
3. Grand Total	306	100.0	$16,298,000	100.0

cused on audiology and hearing science. These 13 grants received $772,000 (18.5%). There were 3 (4.3%) grants with more general emphasis in communicative disorders, and 3 (4.3%) grants devoted to speech pathology. These latter two categories received $222,000 (5.9%) and $168,000 (6.4%) respectively, of the funds expended for training programs in the communicative sciences. There were no programs having as their primary purpose the preparation of investigators of central communicative processes, although some opportunity for such specialization was available in the aforementioned training programs that focused on communicative disorders. Probably the outstanding feature evident from the foregoing statistics is that there has been a heavy concentration on training programs in otolaryngology. This situation has, of course, been consciously nurtured by NINDS for the purpose of developing a stronger and more viable body of research in clinical phases of the field. Such an emphasis may at first seem paradoxical, since as you will recall from data reviewed earlier in this chapter, these proportions are sharply reversed when one considers the extramural research grants which NINDS was supporting. Here projects in basic science rather than clinical projects predominated. The important fact which is thus demonstrated is that a sizeable number of research scientists capable of working on non-clinical problems have come into the communicative field from other disciplines. This means that NINDS has received relatively few requests for support of programs to train persons for research careers in basic communicative science. It also means that the prime need has been to nurture training programs which would enlarge our pool of clinical researchers.

2. Awards to Individuals. Turning to the subject of grants made to individuals so that these persons might obtain special research training, a sharply different picture emerges. Table 2-26 indicates that in 1968, only 8 (6.5%) of the 123 persons receiving Post-Doctoral Fellowships from NINDS were preparing for research in the communicative sciences. Concurrently, only 12 (5.9%) of 202 Special Fellowships were granted for advanced training in these areas. By contrast, 13 (12.4%) of 105 Developmental Research Career Awards were for work in these areas, as were 2 (14.3%) of 14 Research Career Awards (whose recipients participate in the training of others).

One may also determine from Table 2-26 that the ratios of money expended to support the various types of awards just reviewed parallel the ratios of recipients in the communicative sciences fairly closely. Remembering that 23 percent of the funds NINDS allocates for formal training grants is given to communicative sciences (see Table 2-24 again), the fractions of persons receiving individual awards from NINDS in this area are startlingly low. One is forced to the conclusion that smaller percentages of persons are going on for advanced research training in communication science that would be expected in view of the magnitude of the Institute's support of institutional training programs.

Several additional facets of this situation become apparent when one examines Table 2-27, which shows the distribution of individual awards within the realm of human communication and its disorders. For one thing, only 12 (35.3%) of the 34 indi-individual awards in communicative science are for research training in otolaryngology. However, 6 of these 12 awards were for advanced training of the type offered by a Special Fellowship. Another feature of interest is that half of the Research Career Development Awards were allocated to persons working in audiology. Finally, it is noteworthy that, while there were a total of 9 (26.5%) awards designated as being in the general area of "speech and hearing," not one of these 9 was specifically designated for specialization on either speech processes or on central communicative processes alone.

The foregoing picture is not complete, however, until one also takes into account the information on those post-doctoral trainees who received their support directly from NINDS training grants rather than through individual awards.

A total of 299 such trainees were in NINDS programs in the communicative sciences during 1968. Information as to the specific areas of concentration is available on these trainees. Their distributions are catalogued by percentages in the last column of Table 2-25. Note that 74.1 percent of these 299 trainees were concentrating on otolaryngology, 13.9 percent on hearing disorders, 3.5 percent on speech disorders and 8.5 percent on communicative disorders

TABLE 2-25. Distribution of the 69 Training Grants in Human Communication and its Disorders Supported by NINDS in Fiscal Year 1968.

(Derived from Director's Annual Report, 1968)

Field of Training	Grants*		Funding		Post-Doctoral Trainees †	
	Number	Per Cent	Amount	Per Cent	Number	Per Cent
Otolaryngology	50	72.6	$2,605,000	69.2	222	74.1
Communicative Disorders	3	4.3	222,000	5.9	25	8.5
Hearing Disorders	13	18.8	772,000	20.4	41	13.7
Central Disorders	0	0.0	....	....	....	....
Speech Disorders	3	4.3	168,000	4.5	11	3.7
Total	69	100.0	$3,767,000	100.0	299	100.0

* Prorated where multiple fields were involved.
† From data available on 299 post-doctoral trainees.

TABLE 2-26. Distribution of Individual Fellowship and Career Awards Supported by NINDS in Fiscal Year 1968.

(Derived from Director's Annual Report, 1968)

	Fellowships				Career Awards			
	Post-Doctoral		Special		Developmental		Senior	
Field of Award	No.	Amount	No.	Amount	No.	Amount	No.	Amount
All except communicative science	115	$958,000	190	$2,151,900	92	$2,054,500	12	$329,600
Communicative Science	8	68,000	12	151,100	13	286,500	2	60,400
Total	123	$1,026,000	202	$2,303,000	105	$2,341,000	14	$390,000

TABLE 2-27. Distribution of Individual Fellowship and Career Awards in Human Communication and its Disorders Supported by NINDS in Fiscal Year 1968.

(Derived from Director's Annual Report, 1968)

	Fellowships				Career Awards			
	Post-Doctoral		Special		Developmental		Senior	
Field of Award	No.	Amount	No.	Amount	No.	Amount	No.	Amount
Audiology	....	....	....	....	7	$148,000	1	$29,300
Otolaryngology	2	17,500	6	$ 84,900	4	91,600	....	....
Sensory Physiology	3	24,100	1	12,200	1	22,400	1	31,100
Speech and Hearing	3	26,300	5	54,000	1	24,500	....	....
Total	8	$67,[illegible]	12	$151,100	13	$286,500	2	$60,400

in general. The most obvious interpretation to be derived from these facts is that, since these distributions parallel closely the ratios of training grants in these same areas (See Table 2-25), the individuals thus supported were receiving research training via NINDS training grants in the proportions which one would expect from the concentrations of money NINDS is awarding in these areas to medical schools and other NINDS support to universities. However, note should again be made of the fact that attention to central communicative processes and speech processes is conspicuous by its scarcity.

Finally, it must be observed that NINDS has taken special cognizance of the need for research personnel in the communicative sciences by allowing institutions holding training grants designated as being in audiology, in speech pathology or in communicative disorders to award pre-doctoral traineeships in addition to post-doctoral traineeships. The rationale for this action is that the tremendous demand for high level clinicians and administrators in the aforementioned areas, coupled with the heavy Federal support for pre-doctoral training of such clinicians and administrators (see next section), was diverting potentially competent researchers away from investigative careers into strictly clinical careers.

During Fiscal Year 1968, 12 of the training programs supported by NINDS enrolled an additional 61 pre-doctoral trainees who were preparing for research and teaching careers. Seventeen of these individuals were specializing in audiology, 14 in speech pathology, 9 in speech pathology and audiology, 7 in communicative science, 12 in communicative disorders and 2 in sensory physiology. Thus, the total number of trainees supported directly was 360 persons (299 post-doctoral and 61 pre-doctoral).

B. *Support from Other Federal Programs.* Other Federal agencies also make substantial awards for training of professionals in the fields of human communication and its disorders. However, almost all of this support has as its purpose the preparation of individuals skilled to work directly, either as special teachers or as clinicians, in alleviation of communicative disorders. These training activities have been fostered both through grants directly to educational institutions and through the awarding of traineeships and fellowships directly to individuals. Funding has been through various divisions of the Department of Health, Education, and Welfare. The general scope of these training activities, as revealed by data presented by DHEW during the 1968 budget hearings, is presented in the following paragraphs.

One feature of the Federal programs we are now considering is that they embody an interesting division in the academic levels at which different kinds of training are given support. Federal assistance is being given to both undergraduate (prebaccalaureate) and post-baccalaureate preparation for work with the deaf. In the areas of clinical speech pathology and clinical audiology such assistance has been exclusively at the graduate level, with major but not exclusive emphasis on funding types of preparation which terminate for the trainee with receipt of the master's degree.

Two organizations within the Department of Health, Education and Welfare have carried the responsibility for Federal encouragement in preparation of professionals to deal with problems of the deaf. These are the Social and Rehabilitation Service (formerly Vocational Rehabilitation Administration) and the Office of Education.

Several years ago, the Vocational Rehabilitation Administration (VRA) began support of a specialized training program at the master's degree level which was designed to prepare a small number of persons for leadership positions in rehabilitation of the deaf. In 1967 there were 8 teaching grants and 81 traineeships awarded for these purposes. These were funded in the amount of $551,000.

It is estimated that there is annual need for 500 new teachers of the deaf plus 300 to overcome existing shortages and attrition. Special Congressional appropriations have been available since 1961 to combat this deficit and, more recently, also to prepare college instructors, supervisors, administrators and research personnel in this field. In 1966-67 approximately $2,752,000 was utilized for this program, and it was expected that the expenditure would remain about the same in 1967-68. The exact number of trainees was not reported, but there were several hundred, and at least 45 institutions were awarded grants by the Office of Education to finance undergraduate and graduate training in these areas.

Support for clinical training in speech pathology and audiology has also come primarily through VRA (now SRS) and the Office of Education, but some monies have been allocated through other channels.

It was stated during the 1968 budget hearings, "Approximately 800 students are completing their studies at the master's or doctoral level each year. This number represents about half those needed to reach the goal of 20,000 trained clinicians in practice and 1,500 graduates a year." Estimated manpower figures in speech pathology-audiology for 1968 were that there were 1,670 persons enrolled in graduate programs in speech pathology and audiology, fifteen hundred working for master's degrees and 170 being pre-doctoral. These figures differ radically from the tabulation reported earlier in this chapter from Knower (*op. cit.*) because the earlier tabulation is based only on theses and dissertations reported to Knower. Many M.A. programs do not require a thesis.

VRA expended $3,267,000 during 1967 to support the aforementioned training. This sum was used to finance 678 traineeships and to subsidize the graduate programs for these students in 61 educational institutions. The purpose of these grants was to increase the number of speech and hearing specialists qualified to diagnose and to treat adults with communicative disorders. Teaching grants were made to assist universities to expand their programs and to modify their curricula so as to provide more extensive preparation for work with adults. Such programs had previously tended to prepare their students to work with children in the public school system, and a strong emphasis in this latter direction has continued.

The Office of Education has concurrently supported training of speech and hearing specialists to work with children. In 1966-67, approximately $2,619,000 was available for this purpose. These funds supported 14 program development grants plus 1,397 fellowships and traineeships (many of which were short term traineeships).

During 1967, the Neurological and Sensory Disease Control Program within the Public Health Service continued its support of 8 training programs in speech pathology and/or audiology. Commitments to these programs totalled $466,000. In addition, 70 persons were awarded individual traineeships, in the amount of $300,000, for the purpose of preparing them for professional service to the communicatively handicapped.

The Children's Bureau of the Welfare Administration (DHEW) supported training programs during 1967 in 6 medical schools for the purpose of training professional workers in speech pathology and audiology. Among other things, these schools award more than 30 fellowships with the funds thus available.

Finally, a few fellowships leading to the doctorate in communicative disorders have been available through grants under the National Defense Education Act, and possibly, a few more through the National Science Foundation. Information on the actual number of these is lacking. The important thing to note here is that, unlike almost all other forms of training supported outside NINDS these fellowships are designed to prepare university teachers and researchers.

In summary, Federal agencies other than NINDS are also engaged in large efforts to support training of skilled personnel in the fields of human communication and its disorders, including a very substantial program in education of the deaf. These efforts are primarily made through channels within the Department of Health, Education and Welfare. Their primary purpose is preparation of teachers, clinicians and administrators whose goal will be to supply services for children and adults with communicative problems. Our Subcommittee has not been able to ascertain the exact costs of these endeavors, but the items listed in the preceding paragraphs indicate that better than $9,000,000 have recently been spent annually for such purposes by Federal agencies other than NINDS. Moreover, although again exact numbers are elusive, these expenditures have helped mobilize educational facilities serving a total of at least 380 individuals preparing for work with the deaf and 2,000 preparing to cope with other kinds of problems. A fraction of these students have taken pre-baccalaureate work, but the heavy majority have worked toward master's degrees. Another fraction have been in the post-master's and predoctoral categories. Finally, of course, it must be re-emphasized that an extremely broad array of curricular sub-specialties are included in the overview just given. These range from the curricula that prepare university juniors and seniors to teach academic subjects in schools for the deaf to curricula for experts in language disorders of the centrally impaired or curricula in clinical audiology. Bearing in mind the diversity of sub-specialties involved and the prevalence of communicative disorders in the population, the overall endeavor just described is certainly far from having reached its logical saturation level.

C. *Support from Non-Federal Sources.* No definitive information is known to our Subcommittee as to the amount of non-Federal support for training in communicative science and communicative disorders. Mention was made earlier of the fact that a substantial number of colleges and universities offer such training and that their own budgets absorb large portions of the costs for facilities and faculty. These institutions also have a variety of locally and/or non-Federally funded fellowships and assistantships. However, any guess the Subcommittee might make as to the dollar amounts involved in the above types of support would be strictly speculative.

One can nonetheless gain some idea of the magnitude of the non-Federal endeavor here by considering a few statistics on the number of training programs and on their enrollments. To this end, consider data reported by the American Speech and Hearing Association in 1966 (Opportunities for Graduate Education in Speech Pathology and Audiology, *8,* 1966). The Association here indicated that 151 colleges and universities were providing graduate education and training in this field. The statement also tabulates the kinds, though not the amounts, of financial support these institutions had available for students. We conclude from this tabulation that 103 of these 152 institutions involved offered not only fellowships and assistantships paid from university funds but also Federally-funded fellowships or traineeships. There were 30 schools which gave graduate students support only via the university's own coffers, while 13 schools utilized only Federal support. Six schools did not have any source of financial support for graduate students.

The American Speech and Hearing Association's reports do not include data as to the total number of graduate students enrolled in graduate training programs. Limited information of this type is, however, available from statistics compiled by the National Center for Educational Statistics (*Enrollment for Master's and Higher Degrees,* Fall, 1964, Office of Education) in its nationwide survey of students enrolled for graduate degrees in many fields. This survey tabulates only 108 institutions as having graduate programs in speech and hearing. These institutions enrolled 2,146 students in speech and hearing during the fall of 1964. Their distribution was as follows: 1,572 first-year students, 522 intermediate students and 52 terminal students.

One may make two interesting extrapolations from these data. For one thing, since they were derived in 1964 from reports from only 108 institutions and since there are now more than 135 active graduate programs in speech and hearing, the number of students now in training is undoubtedly at least 50 percent greater than reported by the National Center for Educational Statistics. If one conservatively rounds this extrapolated increase to 3,000 current students [1] and compares this figure with our earlier estimate of a little over half of that number of graduate students receiving Federal support (see preceding section of this chapter), it is apparent that other sources contribute a very large portion of our national expenditure for training of professional personnel equipped to work in the areas of human communication and its disorders. It would not be amiss to estimate this expenditure to at least equal the contribution for the same purpose from all Federal sources combined.

D. *Summary on Support of Training.* NINDS is spending almost a quarter of its training grant funds (almost $4,000,000) to support programs for training investigators in communicative sciences, both basic and applied. About three quarters of these funds are directed toward the field of otolaryngology. By contrast, other Federal agencies are expending at least twice this amount to foster programs whose primary aim is to prepare teachers, clinicians and other service personnel for non-otolaryngologic work with communicatively disordered persons. The non-Federal effort supplies about as much again; and it, too, fosters preparation of a majority of service-oriented graduates. These disparities appear more strikingly in somewhat different statistical form when one considers numbers of individual awards. NINDS supported 360 persons (mostly in otolaryngology) through training grants and an additional 20 persons via the mechanism of individual awards (excluding 15 career awards). Other sources (both Federal and non-Federal) subsidized about 3,000 graduate students, most of whom were working at the pre-master's level. Two things are clear from the overview thus obtained. First, while NINDS is currently engaged in a substantial thrust to enlarge the nation's pool of communicative scientists, even larger endeavors with other purposes are absorbing the main training efforts in the field of human communication and its disorders. Second, NINDS stands alone as the primary champion within the Federal establishment for preparation of research personnel dedicated to exploring human communication and its disorders.

VII. CONCLUDING COMMENT

The salient highlights of the foregoing chapter may be summarized as follows:

1. About 8,500,000 Americans have either bilateral or unilateral hearing impairments of handicapping magnitude, another 2,100,000 have central communicative disorders of significant degree, and 10,000,000 have speech disorders of importance.
2. Approximately one-fifth of these individuals (about 4,000,000) are under 21 years of age, while at least a third of the total (about 7,000,000) suffer marked disadvantage in their educational, social or economic endeavors.
3. The direct costs incurred annually by the nation in coping with communicative disorders totals $500,000,000.
4. The annual loss of earning power due to communicative impairments approximates $1,750,000,000.
5. No monetary value can be assigned to the personal tragedies and social misunderstandings which communicative disorders bring their possessors.
6. NINDS supports about one-third of the nation's catalogued research on human communication and its disorders, while other segments of DHEW support another third.
7. More than half of this research focuses on hearing processes, and within NINDS the proportion rises to 80 per cent.
8. NINDS expends almost a quarter of its training grant funds in the area of communicative sciences.
9. Other Federal agencies spend even more than does NINDS for professional training in the area of communicative disorders, but only NINDS has accepted the clear committment to train both investigators and the teachers of investigators.

Finally, if one draws together various statistics surveyed in this chapter into one overall generalization, that generalization can take the following form. About one American in ten has a communicative problem of noteworthy proportion. The aggregate costs (direct and indirect) of these disorders is about $2,250,000,000, or $100 per handicapped individual. Our expenditures for both research studies and for all professional training in this area total less than $30,000,000, so that these long-term efforts to eradicate the impact of communicative disorders receive less than 1.5% of the current costs of such disorders. This ratio brings our current bill for research and training to about a dollar and a half per handicapped person. If we restrict our computation only to the expenses of research and of the training of investigators, the cost-per-handicapped-capita drops to about seventy-five cents annually.

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[1] This estimate is supported by the fact that 1696 persons were granted advanced degrees in this field during 1968. The distribution of these degrees was 1567 master's degrees and 129 doctor's degrees (Fricke, *op. cit.*) Remembering that substantially more than a year is often required even for a master's degree, one may assume that nearly as many additional graduate students were also enrolled in the fields with which we are interested.

Chapter 3—RESEARCH ON HEARING

I. INTRODUCTION

The procedure followed by the Subcommittee in obtaining a resumé of the research accomplishments and deficits in the area of hearing was first to prepare a detailed outline covering the scope of topics to be reviewed. This outline was then subdivided into blocks of topics which were each cohesive. The Subcommittee next requested an authority particularly familiar with research within one block to prepare a summary statement of research accomplishments and needs in that particular subarea of the hearing field. A total of 68 consulting authorities participated in this endeavor. Their summaries varied in format and style, but all were very helpful.

The present chapter is a resumé and distillation from the aforementioned summaries. Of course, it is immediately obvious that the present chapter can only mention a few highlights and still remain within reasonable length. The Subcommittee's outline itself ran to 57 typewritten pages, and it did not divide all topics in as much detail as some of the authorities felt it should have done. Also, the scope of subject matter was so great that it proved impractical to assemble a definitive bibliography. Nonetheless, the Subcommittee hopes that this chapter will give an adequate indication of both the status and deficits in our contemporary knowledge of hearing and its disorders.

The remainder of this chapter is divided into 3 main headings. These are: 1) The Auditory System and Its Functions, 2) Pathology of the Auditory System in Relation to Hearing and 3) Educational and Rehabilitative Management of Auditory Disorders.

II. THE AUDITORY SYSTEM AND ITS FUNCTIONS

A. *Status of Contemporary Knowledge*. The following review is divided into seven sections.

1. Anatomy of the Ear. The general anatomy of the ear, like other aspects of the anatomy of vertebrates, was vigorously investigated during the latter part of the 19th Century and has not since then had anything approaching the same level of attention. This early attack yielded an abundance of excellent information, but left many vague and open areas that have only occasionally been filled in. Departments of anatomy now are found almost exclusively in medical schools, and exist primarily for the instruction of first-year medical students. They are not often engaged in extensive programs of research in general anatomy, though there are some that have made important contributions.

The invention and perfection of the electron microscope has led to a resurgence of microanatomy, and work is going on to improve our understanding of fine cell and tissue structure. This work has included the ear to only a modest extent in this country, though there has been considerable progress in this area abroad, especially in Sweden.

The general gross anatomy of the normal adult human ear is well known. The normal forms and characteristics of the external ear, including auricle, external auditory meatus, and tympanic membrane, have been thoroughly worked out. The middle ear structures also have been painstakingly described. The anatomy of the cochlea has been studied extensively, but there is uncertainty about a number of features such as the true form and attachments of the tectorial membrane, the forms of the rods of Corti, and details of the innervation of the hair cells.

The normal range of variation of the above structures is less well known than the typical forms. Concerning the clinical variations of the structures, and the relations of these variations to disease conditions, our understanding is very limited. This limitation is particularly serious in the areas of histoanatomy and histochemistry, and in relation to the processes of tissue repair after injury and disease.

2. The Physiology of the Ear. The physiology of the ear is less well understood than its anatomy. Though we have reasonable hypotheses about the operation of most of the structures, there are points of uncertainty about many of them and details are often lacking.

a. Sound conduction. The conduction of sound by the ear is fairly well understood, though some details are unresolved. There is uncertainty about the normal range of variations in the conductive processes, and especially about the effects of age. Bone conduction is much less understood than air conduction.

The action of the tympanic membrane in response to different frequencies and intensities of sound is understood in a general way but not completely, and we know comparatively little about its dynamic characteristics. The same is true of the ossicular chain, and especially the stapes. Our understanding of the tympanic muscles is still incomplete.

b. Cochlear processes. We have acceptable hypotheses about the operation of most of the structures of the cochlea, but many details are lacking. There are several cell groups and tissues, such as the Hensen cells, internal and external sulcus cells, Boettcher cells, stria vascularis, and portions of the spiral ligament, that in appearance seem distinctive and highly specialized but whose functions are only guessed at or are completely unknown.

There is uncertainty about the action of the tectorial membrane in the stimulation of the hair cells, and the particular manner in which these cells operate in exciting the cochlear dendrites. Various formations have been given as to the roles of the alternating and direct potentials in this region.

The electrophysiology of the cochlea has had extensive study and much has been learned about this subject, but many uncertainties remain. Important questions are raised concerning the cochlear (alternating) potentials, their origin and the source of the energy that they represent. Other questions are concerned with the direct potentials: their manner of production, their relevance to the alternating potentials, and whether they play any direct role in the excitation process.

Of interest in this connection is what is known as electrophonic hearing: the responsiveness of the ear to applied electric currents. This phenomenon gains importance from the often considered possibility that hearing of a useful nature can be aroused by electrical signals in the absence even of the cochlea. The evidence in this area is greatly confused and contradictory, and no firm conclusions are now possible.

3. The Auditory Nervous System. The general areas and pathways of the auditory nervous system are known, but again fine details are lacking. A great many studies have been concerned with the projections of the cochlear nerve fibers upon the nuclei of the brain stem and the connections to higher centers, up to the auditory cortex. These relations are extremely complex and so far are only vaguely understood. Lorente de No recognized 13 different areas in the cochlear nuclei to which the primary fibers make connections, but we do not know whether these areas differ in functional significance or specifically where their secondary fibers go. The auditory nervous system has numerous connections to motor systems—eye reflexes, postural reflexes, and the tympanic muscle reflexes—arising in the trapezoid body, olivary complex, nuclei of the lateral lemnisci, and medial geniculate bodies, and no doubt also in the temporal cortex—but we are far from having a clear knowledge of the pathways involved.

An efferent system of nerve fibers has been traced to the cochlear hair cells, but its functional significance is still in doubt. Stimulation of this system has been shown to have an inhibitory effect upon the efferent cochlear fibers, but this effect as thus far demonstrated seems surprisingly slight, and the true role of the efferent system is still to be discovered.

A number of studies of the temporal cortex have revealed some kind of pattern of distribution of cortical activity as a function of tonal frequency. Three or four projection areas (some say as many as nine) have been identified in the cat and the dog, with varying degrees of specificity. Little work of this kind has been done with primates. The study has not been extended to other mammals and to lower vertebrates to a degree that will permit useful comparisons.

Little is known about the microanatomy of the auditory cortex and the relations to function.

4. The Labyrinth and Vestibular System. Along with the cochlea, the labyrinth as a whole has had extensive study and its general gross anatomy is fairly well known. Our understanding is limited concerning the functions of the various parts.

The bone of the labyrinth, especially in the region of the oval and round windows, has an unusual character and possibly disposes to the development of otosclerotic lesions.

The anatomy of the vestibular system of man is fairly well known. The general forms of the membranous labyrinth and its sensory ending have been examined in detail.

The comparative anatomy of this system is less well known because only a few species have been considered in detail—the rabbit, the pigeon, and certain fishes. The functions of the various receptor organs and the degree of correspondence in different vertebrate groups are still uncertain. Little is known about the gravity and motion receptors of invertebrates, though in many respects these seem to resemble the vertebrate systems.

We do not yet know the specific functions of the different vestibular organs—the utricular and saccular maculae and the cristae of the semicircular canals. These functions are less understood in man than in some of the lower animals, and species variations still confuse the situation.

Considerable progress has been made lately, mostly in foreign laboratories, in the study of parts of the labyrinth with the electron microscope, but this work has not been paralleled by the consideration of functional relations.

Knowledge is lacking concerning the labyrinth fluids and the possibilities of fluid exchange between meningeal and perilymphatic spaces, and the origin and disposal of endolymph.

Work is going on, almost wholly on human subjects, on the effects on the labyrinth of abnormal conditions encountered in space vehicles, such as weightlessness, high gravitational forces, and rotation. As yet the work in this area is somewhat fragmentary, and the results have not been suitably assimilated to general knowledge about the vestibular system.

The relations of the labyrinthine organs to the eyes and the eye-muscle system have had extensive study, but many uncertainties remain. Of special importance is the relation of the labyrinthine system to eye-muscle control, both under normal conditions and in the presence of disturbances of either the labyrinth or the visual system.

Much attention has been given to labyrinthine disorders, because these disorders cause disturbances of posture and motor activity and are crippling when severe. Though many symptoms of disorder are recognized, it has been difficult to identify distinct disease entities. The symptomatic patterns are similar for various disease states, and subtle signs have to be looked for to distinguish the differences. A labyrinthine disorder of particular concern is Meniere's disease. It is still mysterious as to cause, and there is great uncertainty about treatment.

5. Embryological Development. Our understanding of the embryological development of the ear in relation to its function is only at an elementary stage. Among mammals only a few groups of animals—opossums, rats, mice, and rabbits—have been examined sufficiently to show in a general way the course of structural differentiation and the development of effective hearing. Many details are lacking, and we need especially to understand the conditions that bring about the first stages of function and the rapid extension of frequency range, dynamic range, and sensitivity.

Our knowledge of the development of the human ear is meager, and we know almost nothing about the functional relations. Our uncertainty extends through the fetal period into the period of infancy and early childhood. Here the embryological problems merge with problems of communication.

6. The Phenomenon of Hearing. Many aspects of normal auditory response and experience have been intensively investigated but much still awaits discovery.

a. Audiometric methods. Many of the methods used in auditory measurements come from the general field of psychophysics, and have been the subject of intensive study for about a century. A recent development in this area—or, more correctly, an extension of principles that have had a long history—is detection theory, which considers the nature of discriminatory processes and the procedures by which they may be refined and quantified.

Methods for the testing of hearing in animals by conditioning and training have undergone great elaboration in recent years, and in some ways perhaps have reached a level of complexity beyond what is really necessary to obtain reliable measures of auditory capabilities.

Clinical audiometry also has had much attention, but for the most part the procedures have been restrained by limitations on the time that physicians have considered appropriate for them and their patients to devote to the testing task. New procedures have been devised, and many of these have proved to be of great value in diagnosis and in the evaluation of therapeutic methods but have not had extensive use because of the time limitations imposed.

There has been a special interest in the development of objective methods of testing hearing. Such methods are most important in the testing of young children and subnormal persons. Many of these, like operant conditioning tests, electroencephalography, and cochlear potential measurements, have been investigated and show a certain promise, but have not been developed to the stage of a routine procedure. The use of computers for programming these tests will no doubt save much time and improve their usefulness.

b. Sensitivity of the ear. The sensitivity of the normal human ear under ideal conditions of listening is very well known. Unfortunately, the standards of normality, and hence the calibration of audiometers, have been much confused in this country because of poorly designed and poorly administered field tests of large populations. A much delayed effort has been made to remedy the situation by the adoption of new standards, and in time this remedy may become effective, but for a while the use of two different sets of standards will cause some confusion.

The amount of variability among normal, healthy ears is still uncertain because of a failure in many experiments to eliminate cases of mild pathology and cases of early pathology with partial recovery.

In survey types of tests, as in other forms of testing, an effort should be made to clarify the relationship between "free field" and "pressure" measurements of sensitivity.

c. Auditory phenomena. The basic phenomena of hearing, including pitch, loudness, beats, combination tones, masking, auditory fatigue, temporal changes, sound localization, and binaural effects, have had extensive study and in general are well known. There are many details, however, that are poorly understood. In many instances we are not able to relate the stimulus dimensions precisely to the subjective phenomena, and even more often we are unable to identify the physiological correlates of the perceived phenomena.

d. Auditory theory. It is the task of auditory theory to establish the correlations between stimulus, mechanical processes of sound conduction, neural activities of the auditory system, and auditory experience. Though there have been notable advances in the last few decades, this task still requires serious effort. A common mistake of theorizers has been to set up part hypotheses: explanations of specific phenomena that are based upon assumptions that have not been tested against the general body of knowledge. Such explanations may seem to serve their purpose for the immediate problem, but their underlying assumptions are often inconsistent with those set up in dealing with a second problem. A stable theory cannot be constructed in this manner; the body of knowledge in an area must be considered in general, and hypotheses must be sought that are harmonious with the whole.

General theories of hearing are concerned with two basic problems: (1) the manner in which various dimensions of stimulating sounds are represented in the action of the cochlea and (2) how these cochlear activities are represented and transformed in the processes of the auditory nervous system. Special theories are aimed at parts of these problems.

It is unfortunate that most of the theories that are commonly classed as auditory theories are of the special type. Almost exclusviely they have dealt with three aspects of auditory experience: with pitch perception, pitch discrimination, and the analysis of complex sounds. Many of these theories offer plausible explanations of the pitch phenomena. However, most of them have not been developed by their authors to the stage where they will account for other phenomena of hearing nor are they in proper accord with the known facts about the anatomy and physiology of the ear. Moreover, if an attempt is made to expand these theories to account for additional facts and phenomena, the effort usually fails.

The most widely accepted theory of cochlear action is the traveling wave theory, which states that stimulation of the hair cells of the cochlea is produced by waves of vibration arising in the basilar membrane at its basal end and moving apically along this membrane with continual changes of wave form, amplitude and phase. Yet there is evidence that is not easily reconcilable with this conception, and other views are still tenable. Further investigation is required to clarify this area.

e. Speech perception. In general, the perception of speech by the normal adult has been covered fairly well. The relationship between the spectral clues available at the moment and intelligibility for different types of speech material has been clarified to the satisfaction of most researchers, and speech audiometry has been refined to a point approaching the limit of its clinical usefulness. However, there remain substantial areas of uncertainty. These include some uncertainty (1) as to the relationship between sensitivity as measured by pure-tone audiometry and by speech intelligibility tests; (2) as to how the frequencies critical to speech intelligibility vary with background noise; (3) as to the relations among background levels and speech intelligibility in everyday situations where talkers modify their speech intensity to conform to changing background levels; (4) as to the relation between word intelligibility (which is easily measured) and efficiency in more global, everyday listening tasks; (5) as to effects of distortion of speech signals and talker differences on speech intelligibility; and (6) as to the distinctive features of speech intelligibility loss induced by different types of auditory pathology. Furthermore, binaural reception of speech poses a series of phenomena warranting clarification and raising significant theoretical considerations. These phenomena involve differential signal selection when speech is competing with speech. The neurological and attentional interactions are different when both ears are receiving both competing signals than when one signal reaches one ear and its competitor reaches the other. These phenomena offer neurology and experimental psychology a meeting ground for study of an auditor's manipulation of complex, learned and meaningful stimuli.

7. Comparative Studies of Hearing. Numerous problems of hearing in man are clarified by a consideration of the auditory capabilities of other animals, and many of the general principles of audition are crystallized and made biologically meaningful by a comparative approach. Unfortunately we have very little information on hearing in animals other than man himself and a few of the common laboratory mammals. For many of the orders of mammals, including such interesting ones as Monotremes (platypus), Dermoptera (flying lemur), Pholidota (scaly anteater), Tubulidentata (aardvark), Proboscidea (elephant), Hyracoidea (hyrax), Sirenia (manatee), Perissodactyla (horse, tapir), and Edentata (sloth), we have virtually no information. For remaining orders our knowledge is often limited to a single representative—thus we know about the Artiodactyla only from a single study of the sheep, and about the Lagomorpha only from limited work on the common rabbit. The large animals belonging to various orders have rarely been studied, obviously because of the inconvenience in doing so. Rodents have been the most common subjects for auditory tests, and the work has included rats, mice, guinea pigs, kangaroo rats, chinchillas, and occasionally others. The Car-

nivora are moderately well represented, with work on dogs, cats, and raccoons. Bats have excited much interest lately because of their peculiar ability of echolocation, in which hearing is effectively substituted for vision. Our knowledge of echolocation process, however, is still seriously limited. A method of training bats in a laboratory situation has been developed, and we can expect that many questions in this area will be answered. Even more puzzling problems of auditory behavior are found in the toothed whales, which likewise employ echolocation under many conditions. These problems also are under serious attack, and useful results should be forthcoming.

The lower animals—birds, reptiles, amphibians, and fishes—have been considered even less than the mammals, but there are a number of worthwhile studies. Several species of birds have been examined, especially for their song patterns and use of song in communication. Only a minor portion of this work has been done in this country, though interest in the field is developing. The reptilian ear has been largely neglected until recently, when both anatomical and cochlear potential studies have been carried out on a number of species. Among amphibians, research has been practically restricted to the frog, though there are many strange variations in ear structure among other amphibian groups. The work on fishes has been concerned almost exclusively with the bony fishes (teleosts), with a few scattered observations on sharks that are dangerous to man.

A difficulty with many of the experiments on animals is a lack of calibration and control of the stimulating sounds. Often there has been no instrumental calibration, and the sensitivity of the animal has merely been compared with that of a few human subjects tested with the same apparatus. Frequently, also, the measurements have been made in a room or chamber with reverberant walls, and slight movements of the animal's head will produce large variations in intensity of the sounds reaching the ear. Often there has been insufficient control of disturbing sounds from the environment.

Because of these inadequacies in the experimental situation a large number of the tests that have been made of auditory sensitivity in animals will have to be repeated.

In general, even for the common laboratory animals, very little has been done in the determination of frequency discrimination and intensity discrimination. There are a few studies in cats. Little is known about the high-frequency ranges of most animals, except that there are indications that a great many of them have an upper limit of hearing well above man's. For the lower classes of vertebrates—which are cold blooded—the body temperature is an important condition, yet in many of the experiments it has not been controlled.

Little is known in detail about the hearing of invertebrates, though a number of experiments have dealt with this subject. More knowledge is needed on the mechanics of these ears, because of the wide differences from the vertebrate ear.

B. *Research Needs.* The complexities of the auditory system and its functions (ranging along such diverse dimensions as microhistology, comparative physiology, cochlear mechanics, central neurological processes, basic attributes of auditory experience, developmental characteristics, and meaningful interpretation of the acoustic sequences of speech—to name only a few dimensions) obviously require highly diverse research techniques and procedures. As obviously, a comparable spread of significant questions remain unanswered despite the substantial investigative triumphs already achieved. It would be presumptuous for any small group such as our Subcommittee to attempt a full catalogue of these questions even with the help of its many consultants. The reasonable approach is to define relatively briefly some of the major areas involved. It is with this purpose in mind, and with full recognition that no professional worker reading the following paragraphs will feel that they do justice to the research needs of his particular sphere of interest, that the Subcommittee presents the following as a distillation of some of the unanswered questions which were pointed out either directly or indirectly by its consultants.

1. Need for Anatomical Detail. It has already been indicated that our knowledge about the anatomy of the ear is deficient at many points, and especially we lack details such as the attachments of parts and similar conditions that determine the mechanical interactions. Our uncertainties here are in large part a result of the great delicacy of the ear's structures and the changes that take place during histological preparation.

2. Need to Refine Histological Methodology. There is a very great need for an energetic investigation of histological methods for the study of the ear. Ordinary methods do not serve. The ear is a particularly fragile mechanism enclosed (in mammals) in the hardest bone in the body. The methods of preparation used apparently with success for other tissues cause intolerable disruption of auditory tissues. The special procedures worked out long ago by Siebenmann, Wittmaack, Werner, and others by purely trial and error methods are only moderately successful, and there is no doubt that they could be improved by an application of new knowledge about cell chemistry and cell mechanics.

The recent development of interest in "temporal bone banks"—in the collection and processing of the temporal bones of persons with a variety of ear conditions from normal to all forms of deafness—has increased the need for a standard, acceptable, and reproducible method.

3. Need to Study the External Ear. Particular needs include the microanatomy and histochemistry of the skin of the external auditory meatus, its cerumen and sebaceous glands, and the growth and repair of these tissues after injury and disease. We need to know more about the growth and repair of the tympanic membrane, and especially the role of supplementary membranes, artificial supports, and tissue grafts in the closing of a tear or opening in the tympanic membrane. This problem should be related to our general knowledge of wound healing and tissue regeneration.

4. Need to Study the Middle Ear. We should know more about the auditory ossicles, their interconnections and ligamentary suspensions, their vulnerability to injury and displacement, the range and significance of congenital anomalies, and the use and effectiveness of replacement structures. The lever ratio of the human ossicular system is unknown, and should be determined.

Further study is needed of the protective function of the tympanic muscles, especially the stapedius muscle, the innervation of these muscles, and their reflex action.

5. Need to Study Cochlear Structures. Special study is needed of the bone of the cochlear capsule of man (and possibly of other animals), because of the relevance to the disease of otosclerosis. This study should include the embryological development of the otic capsule, modes of ossification, formation of the cochlear windows, the blood supply, and processes of repair and replacement after injury.

Further information is needed on the mode of formation, composition, and functions of the labyrinthine fluids. We need to know how these fluids are maintained and how they are resorbed. Specific questions are the function of the striavascularis in fluid formation, whether there is a third fluid within the organ of Corti called "cortilymph," and the degree of permeability of various membranes of the labyrinth to the fluids and their constituents. Knowledge is needed concerning the activity of various cell groups in fluid formation and modification. We need to know the significance of various ions, especially potassium and sodium ions. Finally, we need to know the effects of disease on fluid production and fluid composition.

6. Need to Clarify Vestibular Anatomy. As already mentioned, the detailed anatomy of the labyrinth has had only limited attention. Much more work needs to be done on a variety of species. The selection should include representatives of all major groups throughout the vertebrates so as to provide a basis for meaningful comparisons. This study should be extended also to invertebrates, for their study may illuminate principles of operation that they share with the vertebrates and perhaps reveal new principles.

A thorough study should be made of lateral line organs and other related organs such as the ampullae of Lorenzini, because these organs resemble the vestibular receptors in many ways.

Special attention should be given to the electrical potentials of the labyrinthine endings, and the action potentials of their nerves, with particular consideration of their relations to function. Electrophysiological methods may prove useful in solving many of the problems in this area.

Specific matters in need of study are the effects of rotation and linear acceleration, patterns of inhibition and reinforcement, and the effects of efferent nerve activity. Also of interest are the effects of pathological conditions such as oxygen deprivation, drugs, toxins, ionic changes, and ultrasound. The relations of the labyrinth to the cerebellum have been long considered, but these relations are still unclear.

A serious attack on special problems growing out of the space program, such as the effects of weightlessness and strong gravitational and rotational forces, should be carried out with a variety of experimental animals. This work should have the object of discovering general principles and producing a systematic organization of the area.

Further work is needed, by advancing methods, on the diseases of the labyrinth, testing procedures, and methods of evaluation of treatments. Little work in this area is going on in this country at the present time, but suitable equipment and procedures have been developed in some foreign laboratories and ought to become known to our researchers and their students.

7. Need to Define Developmental Processes. Further work needs to be done on the embryology of the human ear and likewise on the embryology of the ear of a number of animal species. This study should lead to a general comprehension of the embryology of the vertebrate ear. Of particular interest is the series of developmental changes that mark the first incidence of auditory function and the improvements of performance up to the adult stage. In this connection we need to identify and understand the conditions that bring about a relatively rapid extension of frequency range and of dynamic (intensity) range in the developing ear. This study calls for the design of new methods for measuring auditory sensitivity in young animals.

Special problems in this connection include the ossicular systems of lower vertebrates, especially fishes and amphibians, changes in the structure and function of the amphibian ear during metamorphosis, the amphibian papilla in relation to the basilar papilla, the function of the macula neglecta, the possibility of hearing in cyclostomes, and the auditory nervous system of the lower vertebrates in comparison with this system in mammals. The last topic should include a consideration of inhibitory mechanisms in the cochlear and the auditory neural centers.

Of great importance is the study of hearing in infancy and its growth during the first days and months of life. This research should correlate anatomical and neural changes with changes in auditory function and general behavior and changes in the adequacy of communication.

8. Need for Information on Animal Hearing. As brought out earlier, our knowledge of hearing in animals is lacking in many respects. We are in need of both behavioral and electrophysiological studies of hearing in animals of all sorts, extending throughout the vertebrate series and including also such invertebrate forms as seem to possess auditory capability.

Worthy of particular investigation are the following animals whose ears have undergone special developments: (a) bats, porpoises, shrews, and others that are known to be capable of echolocation or are suspected of this ability; (b) the marine mammals other than the whales, whose ears may have undergone a secondary adaptation to an aquatic medium as the whale ear has; (c) a further study of whales by behavioral methods (there is now one good audiogram for one animal).

Other studies for which the need is acute have a relevance to the problem of the evolution of the ear, and include the following: (a) a consideration of the ear and the possibility of hearing in the cyclostomes, which are the most primitive of the fishes and perhaps represent the forms in which the auditory function emerged among the vertebrates; (b) a thorough examination of various forms of the amphibian ear and its functional effectiveness, with consideration of the great variety of middle ear structures that arose in this group; (c) a further study of the reptilian ear, especially as seen in the lizards, with reference to the probability that this is the most primitive ear in which the place representation of tones along the basilar membrane was brought to a significant stage of effectiveness; (d) a thorough study of the ear of birds, for which we have only a framework of knowledge; and (e) further study of the mammalian ear to include many orders about which nothing is known, and especially to include some of the very large animals.

More detailed points that need to be covered in the above studies include the details of anatomy, which are usually lacking except for one or two common laboratory species, and how variations in these details affect the ear's performance. Thus, for birds, the mechanics of the middle ear has not been approached experimentally, and there is much uncertainty about the structure of the inner ear. The function of the lagena is still unknown in birds as in lower vertebrates. Little is known about the sensitivity of the bird ear, and almost nothing about its frequency discrimination.

Auditory communication in birds is of special interest, and several attempts have been made to study it. One way is to raise songbirds in isolation or in special acoustic environments in order to determine the effects on song patterns. This type of experiment should be pursued vigorously with the aid of modern precision equipment for recording and analyzing the vocal behavior. The production of song patterns needs to be related to auditory efficiency, to the operation of the auditory nervous system, and to general brain function.

There are almost no behavioral studies of hearing in amphibians and reptiles, and surprisingly few in birds. We badly need such studies for their indications of function and to assist our understandings of electrophysiological studies of hearing in these animals.

9. Need to Define Variability in Human Audition. The very extensive knowledge which modern experimentation has given us regarding human auditory phenomena has been obtained primarily on small groups of select subjects. We have relatively little information on individual differences in these phenomena, except in the realm of threshold acuity for pure tone and speech stimuli. There is need to define the variabilities and stabilities of other auditory capacity which characterize both normal and clinical populations. Among other things it is imperative to discover to what degree the findings from intensive psychoacoustic studies on a few selected subjects are applicable to clinical audiology.

A related topic of high theoretical importance for the understanding of human neural function is the problem of determining the parallelism between auditory phenomena and phenomena in other sensory modalities. To what degree, for example, can binaural auditory experience be mimicked by appropriate bilateral stimulation of other sensory systems. Are there important individual differences here? Or, again, are there some attributes of sensory experience, such as differentiation of durations, which are strictly crossmodal and are universal?

Even in the realm of threshold acuity there are important unanswered questions. There is great confusion concerning normal acuity for the extreme high tones, and more work needs to be done on the effects of age, acoustic trauma, and various disease conditions on the upper auditory range. We still lack an adequate method for determining the sensitivity of the inner ear definitively and over the full range of stimuli that is desirable. Perhaps new transducers can be developed or an effective technique for quantitative measurement of the human cochlear potential can be perfected. Again, there has not been full study of correspondences among threshold relations (either absolute or differential) as measured by various psychophysical methods. We also need 1) a definitive method for transferring audiometric norms to new earphone-cushion combinations; 2) improved techniques for testing both very young and neurologically damaged children, which would among other things make better use of operant conditioning as developed by the comparative psychologist; 3) computerized techniques for obtaining both voluntary and involuntary (i.e., electroencephalographic response) simply; and 4) clarification of the effects of various central neural lesions on threshold sensitivity for various types of stimuli. Finally, appropriate data on auditory sensitivity can supply the basis for choice among our current theories on the mechanism of threshold response.

10. Need to Clarify Monaural Auditory Phenomena. Many of the features of auditory experience can be elicited through stimulation of a single ear. Some of these features have been studied in depth but substantial ignorance remains. For example, many aspects of pitch experience are well understood, and these have been the focus for much of auditory theory. Yet aspects of the pertinent theory remain in controversy and varied problems need investigation. One thinks of such topics as 1) the effects, if any, which sound intensity has on pitch perception and pitch discrimination; 2) the effects which duration has on pitch perception in general; 3) the relation which pitch scaling has to critical band width; 4) the insight which study of pitch-memory can give us regarding auto-correlational processes of the auditory nervous system; and 5) spectral factors affecting the apparent pitch of complex sounds.

Analogous uncertainties characterize our knowledge of the loudness experience. Here typical problems in need of investigation include 1) the effects of onset and decay rates on loudness of pure and complex tones; 2) the forms of equal-loudness contours in the low-frequency range; 3) the natures of loudness functions of masked normal ears and of impaired ears; and 4) the nature of loudness adaptation.

We are particularly in need of studies on the analytical capabilities of the ear when stimulated with all kinds of complex sounds from 2-tone combinations to noises with various forms of time, phase and spectrum change. This study should include the "timbre" of musical sounds and of the voice. We particularly need to define better the experiental continuum from simple pure tone to nondescript noise. We must relate the multitudinous "timbres" of meaningful environmental sounds, including speech sounds, to this continuum. Many aspects of the complex psychoacoustical problems in the world of music are also encompassed here.

There are, of course, many other aspects of monaural behavior wherein our ignorances are great. Illustratively, study of masking has recently been resumed, but theoretical explanations of masking remain unsatisfactory. Many aspects of masking await clarification, such as 1) why a later signal can mask an earlier one, 2) what characterizes central masking or 3) how residual masking functions for maskers other than broad-band noise. Turning to other illustrations, both the phenomena of beats, especially the beats of mistuned consonances, and the theory of beats require clarification. So does the nature and source of aural harmonics. The identity, relative magnitude and phases of these harmonics should be clarified and related to the theory of subjective tones. Combination tones also need further study, with particular attention to their magnitudes in relation to the primary stimuli. So does the phenomenon of tonal interference, thus far seen only in the cochlear potential. To generalize, distortion of the ear should receive extensive consideration in forthcoming research on monaural phenomena.

11. Need to Clarify Binaural Auditory Phenomena. Experiences arising when both ears are stimulated are of great importance, and in many respects are poorly understood.

The phenomena of localization continues to require attention for both theoretical and practical reasons. One question of significance is whether time-intensity trading relations evident in laboratory experiments on localization are learned or innate. Again, we need definitive studies on human echolocation (a skill of prime importance to the blind). Likewise, the role in localization of such aspects of binaural stimuli as differences in interaural spectra and interaural cessation characteristics await determination; as do the roles of various auditory clues in judging distance to the sound source. A particularly knotty problem involves defining the cuse (both auditory and nonauditory) affecting such judgments as assigning an external reference to a sound (i.e., sensing it as "out there" at a particular azimuth and distance from the listener). Or, at the level of understanding central neural functioning, we are faced with the task of developing a good theory of bi-cochlear comparison which will account for the fact that interaural time differences measurable in microseconds produce image shifts via a nervous system whose synaptic latencies vary as much as 1 millisecond.

Another major area of research need involves binaural "unmasking," i.e., release from the interference of competing sounds when the relation of the various sounds differ at the two ears. The mechanisms involved have much in common with those mediating localization. These mechanisms have important information to supply regarding both the behavior of the central auditory system and other phases of auditory function (i.e., velocity of traveling wave in human cochleas). Again, the study of masking level differences at low frequencies holds promise of supplying critical information in this stimulus range, where both the analytical processes and experimental attributes of hearing are poorly understood. Most importantly, there is need to determine to what degree the principles of binaural unmasking as discovered through laboratory experimentation operate in everyday situations where complex primary stimuli, such as speech, must be perceived against complex competing stimuli, i.e., other speech or fluctuating environmental noise. Here is an area where the range of individual differences in perception and the effects of training are particularly in need of investigation.

Lastly, there are a variety of other binaural phenomena having both practical and theoretical interest, and thus warranting study. These phenomena range from the experience of binaural beats and the achievement of a single binaural pitch when dyplacusic monaural stimuli are presented simultaneously to the suppression of "echo" interference when listening to competing sounds in reverberant environments.

12. Need to Relate Short-Duration Stimuli to Auditory Experience. There has recently been a very rapid and salutory development of interest in the temporal aspects of hearing, as distinguished from the simple and traditional steady state response. Of special importance here are studies of frequency, amplitude, and phase modulation. This work should be encouraged. It brings out important features of the ear's mechanical performance. It also furnishes the foundation for our understanding of the relation between fluctuations in the sound patterns of speech and the intelligibility of that speech; as well as supplying the foundation for an analogous understanding of other significant environmental sounds.

Two kinds of issue become particularly important in evaluating short-duration and complexly modulated sounds as auditory stimuli. One issue is concerned with the natures of the acoustic dimensions which are critical in producing dissimilar auditory experience, e.g., what is the relation of the "timbre" of a short sound to the configuration of its onset. The second issue is concerned with whether the central nervous system has different durational and configurational "storage" constants for different types of sound, e.g., are the directional, modulational and spectral aspects needed for consonantal discrimination quite different from those requisite to the noting of a phase change in a synthesized experimental spectrum?

13. Need to Clarify Selector Processes in Everyday Listening. The foregoing discussions have made some reference to the special problems of everyday listening. There are unique features and requirements in everyday listening that make it a topic of major research significance—and one which has to date largely defied systematic experimental exploration. There certainly is a great deal which must be done in the way of preliminary laboratory investigation before fully meaningful quantitative studies can be performed extensively in the field. The nature of such preliminary investigation is dictated by the fundamental features of the more exacting listening tasks that characterize everyday life. These features are 1) that significant sounds are either speech or transient meaningful noises, 2) that these acoustically complicated sounds are often distorted by reverberation effects, electronic reproduction, etc. and 3) that competing sounds, including meaningful speech, are often present. These features dictate three major lines of research.

The first line involves further study of acoustic factors in the speech signal which affect its intelligibility. What degrees of distortion are tolerable under what circumstances? How do measures of intelligibility which can be performed in simple test situations relate to more global, everyday listening tasks; and how are these relations modified by electroacoustic distortion, by change in talker, by reverberation effects and by change in auditor?

The second line of research must attack the masking characteristics of complex background conditions. One kind of problem is the question as to how, from the acoustic point of view, interference with understanding of meaningful speech varies as the spectral complexity and modulation pattern of the masker changes. This problem includes the possibility that masking varies substantially from one type of speech-listening task to another, so that the concepts of the AI and the SIL will need substantial modification when the masker is unstable environmental sound. Secondly, we need to know more about how the frequencies important for speech intelligibility shift with change in the spectrum and the level of background noise, even when this noise is relatively stable. The last kind of problem involves the effect which background sound has on talker levels and thus, indirectly, on intelligibility.

The third line of research is in many respects the most important. It deals with the question as to how the nervous system disentangles competing messages, notably competing lines of chatter. Here, despite a few important breakthroughs, knowledge is most limited. We need at the outset to ascertain the parameters and mechanisms that determine human capacity to attend selectively to one talker, heard monaurally, while competing speech is entering the same ear. We need also to achieve a much fuller understanding of the neurological and psychological mechanisms which allow two messages to be kept from interfering with one another despite large intensity disparities when one message reaches one ear and its competitor the other ear. We need to reconcile the existence of this capacity, regardless of the ear being attended to, with the evidence that the left temporal lobe is normally dominant for incoming verbal material. Finally, we need to determine how much and in what ways the task of disentangling two competing speech messages is facilitated by binaural reception, but then how performance is degraded if the competition is complicated by additional talkers and/or other background sound.

14. Need to Refine Auditory Theory. It is unfortunate that most of the theories that are commonly classed as auditory theories are of the special type. They embrace limited sets of phenomena, and they have dealt almost exclusively with three aspects of auditory experience: with pitch perception, pitch discrimination, and the analysis of complex sounds. Many of these theories offer plausible explanation of the pitch phenomena. However, most of them have not been developed to a stage where they will account for other phenomena of hearing, nor are they in proper accord with known facts about the anatomy and physiology of the ear.

The need is for the development of general theories of hearing that embody comprehensive treatment of all available information about the ear and its functioning under both normal and abnormal conditions. Such theories will make the various facts meaningful by bringing them into systematic relation, and in doing so, reveal gaps, inadequacies and inconsistencies in our knowledge and thereby show where further investigation is needed.

There are two basic problems wherein development of general auditory theories could thus forward our knowledge most significantly, 1) the manner in which various dimensions of stimulating sounds are represented in the actions of the cochlea and 2) how these cochlear activities are represented and transformed in the processes of the auditory nervous system. To this end, ample support must be given not only to the laboratory investigator whose experiments gather the data requisite to such theories but also to the creative thinker whose research can supply the integrative theoretical overview.

15. Summary. In general, we need thorough anatomical, physiological, electrophysiological, and behavioral studies on the same ears and for a great variety of animal species. From such data and their intercorrelations we can hope ultimately to gain a true understanding of the operation of the auditory receptor and its service, for man and his fellow creatures, in our perceptions of the world of sound and our communications with one another.

C. *Training Needs.* It must be plainly said that the research personnel available for work in the area just reviewed is seriously inadequate for the kind of program that the situation calls for. Also, as will be pointed out presently, it is not likely that the numbers of researchers can be greatly augmented soon. Hence we can hardly expect in the immediate future to have the breadth of coverage of problems, the quality of research production, and the rate of progress that must be considered desirable and suitable to the need. It is a compelling necessity, therefore, that we utilize the available personnel to a maximum degree and do what is possible to increase the supply.

There are a number of available investigators, even though they are relatively few. What first needs to be done is to increase their effectiveness. Many are working under poor conditions, with outmoded equipment and inadequate methods, and amid manifold distractions and discouragements of many kinds. Some, though certainly not all, of these handicapping conditions can be alleviated.

An increase in investigator effectiveness can be accomplished in three ways. One way, which is within the purposes of this report, is to point out the important research needs and in some respects to indicate suitable methods of meeting these needs. Another way, perhaps the most effective, is to raise the level of financial support so as to provide essential assistance and equipment that will save the time of prime investigators. Good equipment nowadays is expensive, and many laboratories lack the most effective devices. Some of the routine work can often be "subcontracted" to other laboratories that have equipment and service personnel not being fully utilized. If funds were available for this purpose the research would be expedited.

A third way of improving the situation is to reduce the present administrative load on the researcher. This is perhaps the most difficult measure to carry out, but even a slight improvement of existing conditions would be rewarding in increased research output.

Teachers and facilities for the training of new investigators in the area with which we are concerned are very limited. Also, students with proper talents for development in this field are in short supply. A vigorous effort of recruiting students that do have proper backgrounds will be required, and new programs should be set up to train them effectively.

III. *Pathology of the Auditory System in Relation to Hearing.*

A. *Status of Contemporary Knowledge.* The following review is divided into three sections.

1. The Nature of Auditory Impairments. Consider first the main types of auditory impairment and qualities of hearing.

a. Types of impairment. Auditory impairments are most commonly classified on the basis of the locus of the interference to normal hearing function. *Conductive impairments* result from pathology affecting the external ear, the tympanic membrane, or the middle ear. *Sensory impairments* result from lesions within the cochlea. *Peripheral neural impairments* result from lesions of the VIIIth nerve. *Central neural impairments* result from lesions at higher levels in the auditory neural system: in the cochlear nuclear complex and elsewhere in the brain stem, in the thalamus, in the temporal lobes, etc. *Pseudohypacusis* refers to apparent losses in hearing acuity which cannot be attributed to organic lesion.

b. Quality of hearing under conditions of impairment. The most widely recognized manifestation of auditory impairment is reduced acuity (threshold sensitivity). Nevertheless, other—and sometimes even more important—changes in hearing may be present, particularly with sensory and neural impairments. The following tabulation summarizes the auditory behavioral changes, other than changes in threshold sensitivity, which have been associated with lesions in the cochlea, the VIIIth nerve, the cochlear nucleus, and the brain stem and cortex.

Site of Damage: Cochlea.

Usual Manifestations: (1) remarkably keen differential sensitivity for intensity change, (2) abnormal loudness function, (3) mild to moderate threshold adaptation for sustained acoustic stimulation, (4) mild to moderate loss in discrimination for speech.

Site of Damage: VIIIth Nerve.

Unusual Manifestations: (1) poor sensitivity for small changes in sound sensitivity, (2) normal or retarded loudness function, i.e., no recruitment, but possibly decruitment, (3) dramatic threshold adaptation for sustained acoustic stimulation, (4) very poor discrimination for various phonemes of speech.

Site of Damage: Cochlear Nucleus.

Unusual Manifestation: (1) no clearly defined pattern.

Site of Damage: Brain Stem and Cortex.

Usual Manifestations: (1) poor integration of binaural acoustic stimulation, (2) poor capacity to interpret distorted speech stimuli.

c. Quality of hearing following modification. Very broadly, two different types of modification can be considered: modification through surgery and modification through amplification.

The major consideration of surgically modified hearing function has centered on the various surgical procedures designed to reduce or eradicate the influence of middle ear pathology. Most of the attention has been directed toward the changes in threshold sensitivity accomplished by these procedures. There is some evidence, nevertheless, that changes in hearing resulting in either better or poorer speech discrimination are not usually caused by these procedures, but may occasionally occur. Other changes such as hypersensitivity to loud sounds and diplacusis have also been described as infrequent sequalae.

Very few reports are available concerning the quality of hearing following surgical procedures aimed at the alleviation of conditions incurring lesions in the cochlea and in the auditory neural system. Therefore, it is not possible at this time to formulate any generalizations about the changes in hearing which may be effected by these surgical procedures.

There has been extensive discussion of changes in hearing effected by the use of amplification, particularly by the use of wearable hearing aids. Among the factors which have been considered are changes in acuity for speech signals, changes in speech discrimination, changes in the ability to respond to one signal in the presence of competing signals, and changes in the ability to tolerate loud sounds. These changes have been considered as they occur with respect to the amount of amplification provided, the response characteristics of the amplifying system employed, and whether the amplification is directed toward one ear or both ears. Still, despite the plethora of discussion, relatively little controlled experimentation has been reported.

2. Diagnostic Procedures and Clinical Tests. Many types of information can contribute to the differential diagnosis of auditory impairments.

a. Medical history. The medical history serves the basic purpose of familiarizing the clinician with the patient's symptoms and complaints as a guide to subsequent examinations. In addition, however, it may play a major role in the formulation of the diagnosis, i.e., the report of similar hearing impairments in other family members may be important to the diagnosis of otosclerosis. Histories of noise exposure, infectious diseases, or the ingestion of ototoxic drugs may assist in the diagnosis of sensori-neural hearing impairments. Details about the prenatal, birth, and neonatal life of a child may be significant in describing the factors which may underly the lack of auditory responsiveness of young children.

This history interview may also guide the clinician in the formulation of plans for rehabilitation since the patient's previous experiences, his attitudes toward his impairment, and myriad social, educational, vocational, and psychologic factors will have major implications for decisions relative to the optimal course for treatment and for rehabilitative programs.

b. Otoscopic examination. The otoscopic examination serves chiefly to inform the clinician of the condition of the external auditory canal and the tympanic membrane. Adequate examinations frequently entail the utilization of high-power magnification for more precise observation of tissues and such special devices as the Bruning otoscope to determine the movement of the tympanic membrane. If the otoscopic examination yields positive findings, the presence of conductive impairment can usually be established and often classified. On the other hand, if the examination yields negative findings, conductive impairment cannot be necessarily ruled out.

c. X-ray examination. For many years, X-ray studies have formed an important part of the diagnosis of such lesions in the peripheral auditory system as cholesteatoma and mastoiditis. More recently, laminographic and pantopaque techniques have been used for describing congenital malformations of the ear and, predominantly experimentally, diagnosing otosclerosis of both the fenestral and retrofenestral types.

Radiologic evaluations may play an even more important role in the identification of certain retrocochlear lesions. In some cases of acoustic nerve tumor, routine X-ray examination of the petrous pyramids will demonstrate a dilation of the internal auditory meatus. Laminographic studies now permit charting the course of the internal auditory canal and comparing precisely the dimensions of the two canals in the same patient. Pneumoencephalography may permit the clinician to detect the shifts in the position of various structural landmarks within the intracranial cavity which accompany space occupying lesions. Other techniques, such as brain scanning arteriography and pantopaque, rely upon X-ray examination of the skull following the injection of various opaque dyes either into the circulatory system or into the cerebro-spinal fluid. Many clinicians believe that these latter techniques have greatly increased the accuracy of the early diagnosis of acoustic nerve tumors.

d. Hearing tests. Available tests run a broad gamut and can be employed to gather information of diverse kinds.

i. Tuning fork tests. Tuning fork tests, the Rinne, Schwabach, Weber, Bing, etc., are primarily qualitative diagnostic tests. They are, nevertheless, a fundamental part of the standard otologic evaluation. These tests may assist the otologist in the formulation of tentative diagnoses and help them to estimate with fair precision both the type and the extent of the hearing impairment. The limitations of tuning fork tests are widely recognized, but they continue to serve a useful purpose in the initial stages of diagnostic investigation.

ii. Standard audiometry. The basic principles and procedures of standard audiometry remain virtually unchanged since the standardization of the technique more than 20 years ago. The clinical audiogram continues to represent the nucleus of any diagnostic examination and the point of departure for subsequent special test procedures. The audiogram describes threshold sensitivity curves for each ear, by air and bone conduction at octave or semioctave intervals. Hearing loss is expressed on a decibel scale of sound intensity referred to the threshold sensitivity of the average young adult with normal hearing.

The first significant addition to conventional audiometry was the introduction by Bekesy, in 1947, of the self-recording, or automatic, audiometer. In the Bekesy technique, both the frequency and intensity of the test signal are motor driven. The patient records his threshold by controlling the direction of intensity change. Automatic audiometry has had profound effects in two spheres: it has facilitated massive surveys of hearing and it has provided a valuable tool for differential diagnosis.

A second significant addition to standard audiometry was the recommended change in the physical reference, or zero hearing level, of the audiogram. Prior to 1964, American audiometers were calibrated to values based on the USPHS survey of 1935 which were subsequently formalized by the American Standards Association in 1951 into the so-called ASA-51 norm. In 1964, the International Standards Organization (ISO) recommended a new reference level based on international collaborative research. This work was motivated by the recognition that the substantial disagreement between the ASA-51 norm and the norms adopted by other nations confounded the problems of comparing data. The new norm has been widely adopted throughout our country and the changeover will undoubtedly be complete within the next few years.

A third important addition to standard audiometry has emerged from the "Theory of Signal Detectability." This theory was derived from the application of statistical decision theory to the detection of auditory signals. Although little of the formal research in TSD has been directly concerned with problems of clinical audiometry, many of the experimental findings are directly relevant to the clinical measurement of hearing.

iii. Speech audiometry. The purposes of speech audiometry are to define the level of hearing impairment (speech reception threshold or SRT) and to assess the efficiency of the individual in perceiving or interpreting the speech signal at supra-threshold levels (discrimination).

Standard methods define the SRT with spondee words. Speech discrimination is measured with lists of phonetically or phonemically balanced monosyllabic words. Despite many shortcomings, speech audiometry has become an indispensable clinical tool. The spondee threshold is easily measured and highly stable. However, discrimination or intelligibility scores must be considered as relative measures since test performances can be influenced by many variables.

iv. Special hearing tests for the identification of site of lesion.

(a) Identification of conductive impairment. Traditionally, conductive impairment has been described through comparison of measures of threshold sensitivity for air-conducted stimuli with estimates of cochlear reserve. These estimates are most commonly accomplished by utilizing bone-conducted stimuli. Unfortunately, many problems have been inherent in all available methods of bone-conduction testing. The three most critical problems involve the calibration of the system, masking of the non-test ear, and the influence of middle-ear pathologies on responses. The recent development of a commercially available artificial mastoid promises a solution to the calibration problem. The necessity for masking the non-test ear during all bone-conduction tests is generally recognized, but it is clear that there are many instances in which the non-test ear cannot be masked adequately without simultaneously raising the threshold in the test ear. Apparently, the severity of this particular problem has been reduced by the use of narrow bands of thermal noise and of insert receivers to determine the point at which cross-masking first occurs. The most serious shortcoming of bone conduction testing may lie in the modification of response which may be incurred by the impaired conduction mechanism. On the other hand, recognition of these mechanical alterations in bone conduction responses may actually assist in establishing diagnoses. Yet, the clinician must correct appropriately for these alterations if he is seeking an uncontaminated estimate of cochlear reserve.

Dissatisfaction with available techniques for bone conduction testing led to the development of the SAL (Sensori-neural Acuity Level) Test. This test utilizes bone-conducted masking of air-conducted pure tone stimuli as an indirect means of estimating cochlear reserve. Currently, most clinicians believe that the SAL test incorporates even more serious limitations than those inherent in bone-conduction audiometry. Although it does not seem to be a likely substitute for bone-conduction audiometry, it may in certain instances be a useful, though qualitative, adjunctive procedure.

Recently, the measurement of the acoustic impedance at the eardrum has been suggested as a clinical tool for the differential diagnosis of various disorders of the conductive mechanism. Although some promising evidence is available, the usefulness of the method as a routine clinical tool remains to be established.

(b) Identification of cochlear impairment. The auditory behavior that was first thought to uniquely characterize cochlear impairments was "recruitment." Early investigators concluded that loudness grew at an abnormally rapid rate—i.e., "recruited"—as intensity was increased above the impaired threshold in the ear with cochlear disorder. Subsequent observations of a number of other abnormal psychoacoustic features in ears with cochlear impairment suggest that this assumption may represent an oversimplification of an extremely complex situation. Nevertheless, two tests for loudness recruitment have been widely employed: the alternate binaural loudness balance test (ABLB) and the monaural bifrequency loudness balance test (MBFLB). The acoustic impedance bridge has also had limited application as an approach to the assessment of recruitment since the intra-aural muscle reflex is apparently elicited by the loudness of a sound irrespective of its sensation level. If the sensation level eliciting this reflex is substantially less than the normal range of 70-80 dB, loudness recruitment is assumed to be present.

The next characteristic to be attributed to cochlear-impaired ears was hypersensitivity to intensity change. Although many approaches to the assessment of this phenomenon were proposed, none proved particularly effective until the development of the SISI (Short Increment Sensitivity Index) Test. This test has become a standard part of the repertoire of clinical audiologic procedures.

The automatic audiometer invented by Bekesy has enjoyed increasingly wide application in the evaluation of cochlear disorder. Bekesy was the first to observe that in patients with cochlear disorder, the amplitude of threshold tracing (i.e., the range from audibility to inaudibility) was frequently quite small in contrast to the normal range. Although interpretations of the basis for this characteristic have differed, abnormally small amplitude of the Bekesy tracing, especially at frequencies above 1000 Hz is generally considered to be a sign of cochlear disorder.

A closely related phenomenon is the type II Bekesy pattern. This pattern is based on the relationship between superimposed tracings for continuous and for periodically interrupted tonal signals on the same ear. In the type II pattern, the continuous-signal tracing drops below the interrupted-signal tracing in the region of 500-1000 Hz and runs parallel to, but 10-20 dB below the interrupted-signal tracing through the high frequency range.

An important, yet little regarded, aberrant psychoacoustic phenomenon associated with cochlear lesion is aural overload. As the intensity of a tonal signal is raised above threshold in a patient with cochlear impairment, non-linear distortion products appear at a much lower sensation level than in a normal ear. Although a precise test for this phenomenon has been described, neither the test nor the phenomenon itself has enjoyed adequate clinical exploration.

(c) Identification with VIIIth nerve impairment. Some of the most significant strides in diagnostic audiometry during the past decade concern the identification of VIIIth nerve disorders. Initial impetus was provided by the observation of Dix, Hallpike, and Hood in 1948, that although loudness recruitment is characteristically present in cochlear disorder, it is characteristically absent in VIIIth nerve loss. Thus, the direct tests for recruitment, especially the alternate binaural loudness balance test, have assumed critical importance. The SISI test has also been widely used since it is usually negative when VIIIth nerve lesion is present.

Another characteristic of VIIIth nerve disorder is abnormal adaptation to sustained pure-tone signals. This phenomenon is most commonly demonstrated with the Bekesy audiometer. When the patient with VIIIth nerve impairment tracks thresholds for continuous tones of either fixed frequencies or ascending frequencies, the tracings rise to higher and higher intensity levels, indicating abnormal adaptation, or the inability to sustain responses to continuous stimuli. This behavior during the tracking of continuous signals is in sharp contrast to the patient's ability to track interrupted signals. Abnormal adaptation can also be demonstrated with continuous presentation of a tone from an ordinary audiometer; this approach has been somewhat formalized into a "tone decay test" and has had wide clinical application.

Speech audiometry can also contribute to the identification of VIIIth nerve disorders since severe reduction of speech discrimination scores is a common test finding. Because other lesions may incur similar reductions in speech discrimination facility, the intelligibility score itself cannot be considered pathognomonic. Nevertheless, severely reduced intelligibility in the presence of only mild or moderate pure-tone sensitivity loss leads to a strong presumption of VIIIth nerve disorder.

Recently, another promising test procedure has been described. When the silent interval between successive tone bursts is reduced below some critical duration, the patient with VIIIth nerve disorder can no longer maintain a threshold response unless the intensity is raised. This phenomenon has been labeled "critical off-time" (COT). Tests designed to identify this phenomenon have not as yet come into wide clinical use.

(d) Identification of central neural impairment. The most extensive explorations of approaches to the identification of central neural impairment have been reported by Bocca and Calearo. The basic principles appear to be as follows: 1) There is little or no reduction in the pure-tone audiogram on either ear. 2) There is little or no abnormality in any monaural supra-threshold test involving pure tones. 3) The ability to understand speech signals may be moderately to markedly impaired on the ear contralateral to the affected side of the brain. This effect may be enhanced by distortion of the speech signal, either through low-pass filtering, temporal interruption, or acceleration. 4) The ability to fuse coherent binaural signals may be severely impaired. This effect has been demonstrated by splitting the spectrum and delivering complementary bands to the two ears, or by alternate switching between ears. 5) The ability to separate noncoherent binaural signals may be severely impaired. This effect has been demonstrated by measuring speech intelligibility on one ear in the presence of either competing speech or competing noise on the opposite ear.

Electrophysiologic indices of hearing also hold some promise as approaches to the identification of central neural impairment. Although conventional electroencephalic audiometry had not thus far yielded clinically useful information in this respect, the newer averaged evoked response techniques are viewed with considerable optimism by some.

v. Special tests for the identification of pseudohypoacusis. A wide variety of tests have been proposed for the identification of pseudohypoacusis. Among these are the pure-tone and speech Stenger, Lombard, Doerfler-Stewart, Delayed Auditory Feedback, Electro-Dermal Response Audiometry (EDR), Shifting Voice, Eyeblink Response, Switched Speech, EEG Audiometry, Bekesy Audiometry, and various masking procedures. Although many of these tests have had wide clinical application, there is a surprisingly small amount of controlled experimental data relating to the methodology, reliability and validity of the various test procedures. Whatever evidence is available suggests that EDR is the single most effective tool. The most effective behavioral index seems to be discrepancies between pure-tone and spondee thresholds.

vi. Special tests for the identification of hearing loss in infancy and early childhood. The growing emphasis on initiation of educational and rehabilitative procedures at the earliest possible time in the lives of children with significant hearing impairments has engendered concomitant interest in the early identification of hearing loss. Consideration of this

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problem has focused in two general areas: the development of improved approaches to behavioral audiometry and the development of so-called "objective" audiometry. Work in the former areas has concentrated on the selection of appropriate sound stimuli, on more precise subjective observation of infant's behavioral responses to these stimuli, and on approaches to structuring the sound-stimulated behavioral responses of young children so that more consistent observation is possible.

Many workers have voiced strenuous objections to the use of the term "objective audiometry." It has been used to describe those procedures which are not contingent upon the patient's subjective awareness of the stimulus or upon a response which is subject to voluntary control. On the other hand, most of the procedures that depend upon objective physiological response are, in most clinical applications, very subjective in that they are frequently administered in unsystematic ways and are dependent upon the subjective judgment of the tester in the evaluation of the significance of observed responses.

The most widely used physiologic-response technique is EDR. Although for a decade or so this technique was regarded with some favor as a means for describing hearing levels in young children, there has been growing recognition of the shortcomings of the procedure in this particular application.

Electroencephalic audiometry (EEA) has attracted rapidly increasing interest as a means for assessing children's hearing. Once again, however, considerable subjectivity has been involved in interpretation since many spontaneous changes in pattern are identical to those elicited by sound. The use of averaged evoked response to repeated auditory stimuli is showing greater consistency in pattern than the single response to the single stimulus. Nevertheless, the patterns do show considerable variability.

There has also been some exploration of test methods involving human cochlear microphonics, or action potentials. Although of considerable theoretical interest, work in this area is far from widespread clinical application.

e. Vestibular tests. Three types of vestibular testing are widely employed: observation for eyes-open spontaneous nystagmus, postural testing, and electronystagmography. Eyes-open spontaneous nystagmus is rare in endorgan lesions except during vertiginous episodes; when it exists, it is an indicator of CNS lesion. In postural testing, the degree of fatiguability of the provoked nystagmus distinguishes between end-organ and CNS lesions. In nearly all end-organ lesions, the nystagmus will be fatiguable: holding a position will effect cessation of the nystagmus in 30 to 40 seconds. Non-fatiguing nystagmus is indicative of a CNS lesion.

Electronystagmography (ENG) has added new dimensions to vestibular testing by permitting measurement of parameters other than duration. Among these parameters are eyeball speeds (fast and slow components), beat frequency, amplitude of eyeball excursion, etc. The chief contribution of electronystagmography thus far lies in the increased understanding of CNS control of the vestibulo-ocular reflex arc, rather than in the refinement of lesion localization. Experimental evidence is emerging, nevertheless, which points to new opportunities for additional applications of this technique to these problems.

B. *Types of Auditory Pathology.* This discussion is divided into five major parts.

1. Pathology Influencing the Conductive Mechanism. Here the distinction is made between aberrations of the external ear and those of the middle ear.

a. Anomalies and diseases of the external ear. Modifications in the form and size of the auricle may occur either as a result of developmental variations or disease processes. These modifications, however, seldom influence hearing. More severe malformations of the auricle are almost invariably associated with malformations of the external auditory meatus and the deeper portions of the ear.

The external auditory meatus may also be affected by maldevelopment; once again, however, isolated maldevelopment is rare. Secondary narrowing or closure of the meatus may occur as the result of wax plugs, foreign objects, stenoses, exostoses, or infections and tumors. Ordinarily, only complete closure influences hearing.

b. Anomalies and diseases of the middle ear. Pathologic changes of the tympanic membrane may be characterized by changes in thickness, by changes in elasticity, or by perforations. Changes in thickness may be effected by infectious processes or secondarily by the scarring which may result from these processes. Infections and the attendant scarring may influence the elasticity of the membrane. Changes in elasticity may also occur as a part of senile degenerative changes of the drum; however, these changes do not seem to influence hearing significantly. The degree to which perforations will influence hearing is a function of both the size and locus of the perforation. Perforations are particularly serious when they are located in the vicinity of the attachment of the malleous to the drum.

A variety of traumatic developmental and disease processes may disturb the function of the ossicular chain. The continuity of the chain may be interrupted at any point. The chain may become fixed at the malleoincudal articulation, or at the incudostapedial articulation. It may also become fixed to the walls of the tympanic cavity. The presence of fluid in the middle ear may impede its function. Most prominent in terms of influence on hearing is the fixation of the stapes which may occur occasionally as the result of infection or as a congenital malformation, but more commonly, with otosclerosis.

Considerable attention has been directed to the actual basis of the hearing impairment incurred by otosclerosis. During the early stages hearing is probably primarily affected by the loss of efficiency of sound transmission incurred by the mechanical fixation of the ossicular chain and the resultant reduction of motility of the drum membrane. As the fixation continues, its effects reduce the advantage of the normal transformer action of the middle ear, until the ossicular route to the cochlea is no better than the aerotympanic route through the round window. Furthermore, there is a disruption of the normal phase interaction between the oval and round window pathways. During the later stages of the otosclerotic process, the closure of the oval window incurs the gravest effect: the immobilization of the cochlear fluids.

During the past two decades, a number of surgical procedures have been devised to rectify defects of the conductive mechanism. *Myringoplasty* is a tissue graft procedure designed to achieve closure of either central perforations of the drum or replacement of the entire drum membrane. *Tympanoplasty* involves not only the closure of the defective drum, but restoration of the continuity of the ossicular chain as well. *Fenestration surgery* was the first widely applied approach to counteracting the effects of otosclerosis. This procedure entailed loss of the normal transformer action of the middle ear mechanism, and some residual hearing impairment usually remained. Through *stapes* mobilization the surgeon was frequently able to achieve improved sound transmission through the otosclerotic middle ear and improved oval window mobility. However, this procedure has been almost completely abandoned because of the high rate of subsequent refixation of the stapes. *Stapedectomy,* on the other hand, seems to effect lasting improvement. In this procedure an artificial conductive system is introduced. A variety of materials have been used for the construction of this artificial conductive system, among them autogenous and homogenous bone grafts, stainless steel wire, Teflon, and polyethylene.

In addition to those pathologic processes which directly influence the function of the drum membrane and the ossicular chain, secondary influences can be attributed to alterations of the volume of the tympanic cavity and the mastoid air cells by intrusion of fluids or infective processes, or to alterations of pressure within the tympanic cavity effected by closure of the Eustachian tube. Artificial alteration of pressure within the tympanic cavity can be effected by Valsalva's maneuver, which tends to restore to normal a negative pressure, or by Politzer's maneuver, which increases a previously normal pressure.

Hearing may also be affected by tics or spasms of the middle ear musculature. Spastic contractions of the tensor tympani muscle may rarely occur; the resultant movements of the drum and ear noises may be very distressing. Loss of function of the tensor tympani and stapedius muscles incurs a loss of the protective mechanism against over-loud sounds and decrease in strength and rigidity of the ossicular chain.

Temporal bone pathology may result from acute, subacute or chronic otitis media. Cholesteatomas may occur as the result of chronic otitis media. A wide variety of other sequelae of middle ear infection can be described: mastoiditis, petrositis, facial paralysis, epidural and perisinuous absesses, meningitis, labyrinthitis, otitic hydrocephalus, and temporal lobe and cerebellar abscesses. Several different types of neoplasms may also invade the temporal bone. The degree of conductive hearing impairment attending these various temporal bone pathologies will depend, of course, upon the degree of interference incurred to middle-ear functioning.

2. Cochlear Pathology. There is a wider variety of anomalies and diseases of the inner ear.

a. Acoustic trauma. The problem of acoustic trauma has been investigated from a variety of standpoints. Noise risk criteria have been developed and successfully applied in the military and in industry. Programs for the control of noise and for the protection of ears are receiving growing emphasis. Although there has been relatively little direct investigation of noise-induced pathology in the human ear, a substantial number of animal investigations have been reported correlating noise trauma and structural changes in the cochlea using both light microscopic and electron microscopic techniques. In the guinea pig, for example, a noise-induced threshold shift around 4000 Hz corresponds to a localized degeneration of the organ of Corti near the junction of the basal with the second turn of the cochlea. Other studies have reported such noise-induced citochemical and structural changes as a decrease of RNA in the spinal ganglion cells and alterations on the mitochondria of the hair cells.

b. Ototoxic disorders. The largest number of investigations of ototoxicity have centered around the mycin drugs, particularly Dihydrostreptomycin, Streptomycin, Neomycin, and Kanamycin. The effects of salicylates have also been investigated. Several studies have been reported which consider the ototoxicity of certain industrial products, for example CO_2 and other toxic gases, various metals, anilin and nitrobenzol.

Although widely reported in the clinical literature, little information is available about the mechanisms and pathogenesis of certain endogenous agents, for example the toxins of the bacteria of such infectious diseases as diptheria, scarlet fever, typhoid fever, the dysenteries, and brucellosis. The same situation obtains with reference to the effects of certain metabolic, endocrine and collagen diseases such as diabetes, liver and kidney diseases, thyroid disorders, and rheumatic diseaes.

c. Infectious diseases. The pathologies incurred by bacterial infections involving the middle ear, the labyrinth, the venous sinuses, the meninges, and the brain are well established. Much less is known about the precise effects of such viral infections as herpes zoster oticus, measles, mumps, influenza, and poliomyelitis. However, progress in the development of immunizations for certain of these diseases may eventually reduce their significance as causes of hearing impairment. It is widely believed that certain cases of sudden deafness are incurred by viral labrynthitis although the essential nature of this disease is little understood.

d. Vascular disorders. Very little is known about possible vascular disorders of the inner ear. Although it is common practice for otologists to ascribe a variety of auditory and vestibular disorders to such etiologies as hemorrhage, thrombosis, embolism, and vascular spasm, thus far there is no proof that any of these conditions exist. Even in Meniere's disease, the topic of a large body of clinical literature, little, if anything, is known about etiology and pathophysiology.

Among the observations about vascular disorders found in the limited experimental literature are that decreasing either the arterial supply or the venous overflow creates degenerative changes in the inner ear; that the embolic phenomena can be produced in the inner ear by introducing small particulate matter into the vascular system; and that lesions of the apical turn of the cochlea frequently result from vascular lesions.

e. Prenatal disorders. The teratogenic effects of various drugs and infections have attracted growing interest. Both the pathological changes and the clinical manifestations attending the cochlear impairments induced by such maternal infections as rubella, mumps, influenza, infectious hepatitis, and poliomyelitis have been extensively described. Except for some descriptions of subsequent clinical manifestations less is known about the pathologies incurred in the fetal auditory system by drugs ingested during pregnancy.

f. Congenital hereditary disorders. It is now well established that deafness is a common manifestation of many types of hereditary disorders, particularly the inborn errors of metabolism. It has also been demonstrated that congenital hereditary sensori-neural hypoacusis is a recessive trait. On the other hand progressive heredodegenerative sensori-neural hypoacusis, a condition which is frequently associated with pigment degeneration of the retina, appears to be dominant. Little is known about the morbid anatomy of either of these conditions. The association of congenital hearing impairment with a variety of other congenital disorders (for example, with progressive interstitial nephritis in Alport's Syndrome) enforces the necessity of joint investigations of these conditions involving researchers from many different disciplines.

g. Delayed hereditary disorders. Late congenital syphilis is probably the best known cause of delayed hereditary hearing impairments. Another such disorder which has been recently described is atrophy of the stria vascularis. The deafness which attends this disorder appears to result from a biochemical or enzymatic disturbance, with no morphologic changes in the sensori-neural system.

h. Neonatal disorders. Of the neonatal disorders, kernicterus neonatorium has received the widest attention. The essential otopathology of this disorder has never been described and controversies continue around the definition of the locus of the lesion which incurs the hearing impairment. Although clinicians have considered the potential influence of neonatal anoxia and hypoxia on the auditory system, little is known about the cochlear changes which might be thus incurred.

i. Cochlear otosclerosis. The recent literature has contained an extensive number of reports which consider cochlear otosclerosis. Some of these reports attribute the cochlear dysfunction which is found among many otosclerotic patients to degenerative disease of the inner ear secondary to the otosclerosis. Others regard this as a contention which remains unproven. It is quite evident that severe otosclerotic involvement of the petrous portion of the temporal bone results in degenerative changes in the inner ear. However, direct evidence of the usual manifestations of the otosclerotic process within the inner ear have not as yet been well demonstrated.

j. Temporal bone trauma. Most frequently, damage to the temporal bone is the result of a fracture of the petrous pyramid. Although longitudinal fractures may incur damage to the external and middle ear, the capsule of the bony labyrinth is usually left intact. Transverse fractures incur more severe consequences since the fracture usually passes through the promontory, the basal turn of the cochlea and extends into the internal auditory meatus; or it may pass through the oval and round windows into the vestibule and into the internal meatus. The occurrence of both longitudinal and transverse fractures can produce any combination of these structural changes. Transverse fractures usually result in a profound or total auditory and vestibular loss on the affected side.

Cochlear damage secondary to temporal bone trauma is also known to occur without evidence of temporal bone fracture. Hearing loss, particularly in the region of 4000 Hz can occur from blows to the head. This observation correlated with animal experimentation which revealed degeneration of the organ of Corti following blows to the head.

k. Presbycusis. With the ever increasing amount of histopathological material which has become available for study—particularly with correlated audiometric, physical, and microscopic findings—various types of presbycusis are now describable. One classification divides presbycusis into four separate types: sensory, neural, metabolic and mechanical. In the sensory type there is atrophy of the organ of Corti with some ganglion cell degeneration in the basal end of the cochlea. In the neural type there is only a minimal amount of hair cell and supporting cell damage, but marked atrophy and degeneration of the ganglion cells; possibly there is also degeneration of the central auditory pathways. In metabolic presbycusis, structural changes are observable in the stria vascularis with only minimal hair cell loss in the very basilar portion of the cochlea. The structural changes underlying mechanical presbycusis have not been clearly delineated, but the major characteristic is believed to be a stiffening of the basilar membrane.

3. Disorders of the VIIIth nerve. A few pathological conditions damage the auditory branch of the VIIIth cranial nerve.

a. Infectious diseases. Of the infectious diseases that incur VIIIth nerve impairment, meningitis is probably the best known. There has, however, been much speculation concerning a disease called "vestibular or cochlear neuritis." This latter disease produces clinical symptoms of vertigo, hearing loss, and tinnitus which cannot be accounted for on the basis of other than VIIIth nerve pathology. Neuritis of the VIIIth nerve has been implicated as a cause of sudden deafness.

b. VIIIth nerve tumors. A substantial amount of attention from all fields concerned with hearing impairment has been directed, in recent years, to the study of the diagnosis and treatment of VIIIth nerve tumors. Significant improvement has been effected in the accuracy of a variety of diagnostic techniques including audiometric tests, radiographic techniques, and, although less well defined, biochemical tests. As yet, however, no single test or even battery of tests can be considered completely definitive, probably because these tumors vary considerably in size and in the portion of the VIIIth nerve they affect.

Until recent years, reports of surgical treatment of VIIIth nerve tumors suggested that in less than half of the cases was total removal of the tumor effected without severe residual disabilities. Newer surgical procedures however, such as the middle fossa, translabyrinthine, and transigmoid approaches have significantly improved the outlook in the treatment of these tumors.

c. VIIIth nerve degeneration. The causes of VIIIth nerve degeneration are usually atributed to non-specific factors: aging, genetic factors, toxicity, etc. Determination of essential causes depends upon further understanding of the reasons why cells die, a broad area of research which is mainly examining organ systems other than the VIIIth nerve.

Most reports on pathologies of the human temporal bone note that impairments in the organ of Corti are frequently accompanied by impairments of the spiral ganglion cells and the afferent nerve fibers. This loss of spiral ganglion cells is probably even more marked in genetic deafness. Although much more study is needed, there is some suggestion that intact hair cells may be requisite to the anatomic integrity of the nerve cells, but that nerve cells may be absent with the hair cells remaining intact.

The efferent system of the VIIIth nerve has been the object of some study and considerable speculation. This system obviously concerns itself with regulation of auditory input, but the essential nature of this regulation is unknown. It has been suggested that many questions about the variable manifestations of VIIIth nerve lesions may be answered when this efferent system is better understood.

4. Disorders of the Central Auditory Nervous System. Definitive information on the nature and the manifestations of disorders of the central auditory nervous system is sparse and poorly coordinated. The major experimental advances have been primarily through work with animals. Lesion of the cochlear nuclei due to asphyxia neonatorium has been defined in monkeys. The effects of damage to the tracts and other auditory nuclei of the brain stem are less well known. Study of thalamic and sub-thalamic lesions stems from stereotoxic surgery and has taken three forms—electrical recording of single and multi-unit responses to stimulation, direct neural stimulation, and production of destructive lesions. Human subjects have been used more to investigate temporal lobe function and dysfunction. A recent highlight has been development of techniques to demonstrate laterality or dominance of auditory functions in the hemisphere.

On the whole, central auditory processes are so poorly understood that this entire topic is a gap area. Clinical-pathological correlation in the human is a serious lack, as is precise knowledge of the natural history of central hearing disabilities. We also lack systematic cataloging of the relations between the details of surgical lesions and the details of disturbance to auditory and language functions.

5. Pseudohypoacusis. Pseudohypoacusis is simulated hearing loss. It most commonly occurs in the form of malingering, when the simulator is conscious of his deception. Malingerers are more common in populations where hearing loss can bring either monetary gain or special advantages. Other pseudohypoacusics are unaware of simulating an auditory impairment.

Audiological techniques for identifying pseudohypoacusics have become highly sophisticated during the past quarter century. These run the gamut from special applications of pure tone audiometry, through subjective tests developed especially to probe pseudohypoacusis, to methods such as electrodermal audiometry which evoke involuntary responses to sound. Consequently the identification of pseudohypoacusis has become relatively easy. However, very little study has been made of the genesis and mechanisms of pseudohypoacusis. The unconscious variety, in particular, is so poorly understood that some professionals deny its existence as a clinical entity.

C. *Research Needs.* As the foregoing discussion indicates, much is known about the symptomatology of auditory impairments, the diagnostic procedures and clinical tests employed to define these impairments, the nature of auditory pathologies and the methods of treating them. However, the same discussion also makes clear that there remain large areas requiring exploration or clarification through research. The paragraphs which follow tabulate some of these research needs. These paragraphs illustrate the scopes and varieties of investigation involved.

1. Need for Improved Differentiation Among Auditory Impairments. The commonly used classification of auditory impairments into the conductive, sensory, peripheral neural, central neural, and pseudohypoacusis probably remains too broad in its scope. Although a variety of sub-classifications have been suggested, none have achieved common acceptance. Research should continue in areas which will accomplish refinement of classification, so that definable sub-categories can be established.

2. Need for Ascertaining Quality of Hearing Under Conditions of Impairment. The auditory symptomatology of hearing impairments is not fully understood. Among the areas in which scientific knowledge is inadequate are the following three.

a. Pitch discrimination. Our knowledge of this capacity in impaired hearing is most fragmentary. It is a highly complex dimension of audition; investigation is difficult since it involves a wholly subjective parameter. Nevertheless, the problem of pitch distortion and subjective pitch differential between ears is common among clinical cases. It is entirely possible that a technique for measuring pitch discrimination between ears of the same listener, and on an absolute scale based upon normal ears, may offer significant advancement in our knowledge of the impaired ear.

b. Loudness. Hypersensitivity to loud sounds represents another phenomenon which needs extensive investigation. A more thorough understanding of the nature of hypersensitivity could lend a significant contribution to our knowledge of impaired hearing. Although the area presents fewer problems to the investigator than does pitch discrimination, a clear delineation must be drawn between physiological and psychological intolerance or hypersensitivity for acoustic stimuli.

c. Tinnitus. Head noise constitutes one of the greatest challenges in otologic medicine and audiology. This malady should be defined more precisely in terms of type and relationship to specify pathology, intensity, frequency of occurrence and methods for reduction or control. Scientific knowledge regarding tinnitus is not only inadequate, but is antiquated as well.

3. Need to Ascertain Efficiency of Hearing in Everyday Situations. There is demand for further investigation of the prediction, on the basis of clinical tests, of the likely difficulties a patient will experience in everyday situations. Among the questions which merit study are: What is the effect on everyday listening of varying degrees of high tone loss? In unilateral hearing loss, to what extent does the affected ear that is characterized by recruitment, diplacusis or other disorders interfere with hearing in the good ear? Would a complete unilateral loss constitute a lesser problem? How much does a hearing disorder enhance the interference produced by background sounds? How does deterioration in everyday listening efficiency due to a hearing disorder vary with the type of disorder and the nature of the listening task?

4. Need to Ascertain Effects of Treatment on Everyday Hearing Efficiency. Hearing efficiency can be changed in varying ways following treatment. There is particularly pressing need for investigation in three areas.

a. Middle ear surgery. Many aspects of hearing quality following middle ear reconstruction, particularly after a stapedectomy with either the incus or the malleus prosthesis, have not been sufficiently explored. Changes may occur in speech discrimination and in dynamic range in ears with associated or coincident sensori-neural deterioration. Similar phenomena may also be observed among patients with persistent low and high tone conductive impairments despite generally satisfactory surgical results.

b. Inner ear surgery. Recent developments in surgery for pathologic conditions of the inner ear, particularly toward the alleviation of dizziness (shunts, ultrasound, etc.), or for the removal of small acoustic neuromas make possible treatment without total destruction of hearing. Little is known about the characteristics of the hearing which remains following these procedures.

c. Hearing aids. As noted earlier, the total body of research about the modifications in the quality of hearing which are effected by amplification, particularly by amplification with wearable hearing aids, is most inadequate. Virtually every aspect of this area requires additional investigation. Most persons have the blissful belief that amplification restores everyday listening efficiency quite well. This opinion is not supported by the few studies which have sought to define aided hearing efficiency in relatively difficult but environmentally common listening situations.

5. Need for Strengthening Medical History and Otoscopic Examination. All research leading to the more precise descriptions of auditory pathologies, particularly with reference to the subjective experience of the influence of these aberrations, will have eventual implications for structuring the medical history. For example, increased understanding of the genetic bases of various hearing impairments may add increased importance to responses elicited by questions relative to family history.

Although the general purposes and inherent limitations of the otoscopic examination are well-defined, continuing refinement in instrumentation and techniques can be anticipated. Research leading to the fuller description of pathology may also have implications here since presently unrecognized yet visible changes in tissues may conceivably be among the symptoms of currently ill-defined pathologies.

6. Need for Refining X-Ray Examination. The entire field of diagnostic radiology is experiencing rapid advancement both in the number of techniques which are available and in the diagnostic precision of these techniques. Many of these advancements will find direct application in the study of auditory impairment. There is clearly a need for more extensive investigations of the application of polytomography to the diagnosis of ear pathology, particularly in the diagnosis of otosclerosis. The application of newer radiographic techniques to the description of congenital malformations of the middle ear also requires more extensive investigation. Perhaps most important of all is the need for intensified study of the application of such special techniques as brain scanning, pantopaque, and arteriography to the diagnosis of VIIIth nerve pathology.

7. Need for Improving Conventional Hearing Tests. Although tuning fork tests will likely remain a standard part of the basic otologic evaluation, their inherent limitations preclude the likelihood of any significant amount of study relating to their use. By contrast, there are potentially significant areas of investigation in the field of standard audiometry. Particularly promising examples lie in the exploration of clinically feasible techniques of threshold audiometry which are controlled for differences in listener criterion; in the development of suprathreshold techniques as possible substitutes for threshold audiometry; in the investigation of standardized methods for expressing audiometric findings independently of the concept of average normal hearing; and in the acquisition of new insights into interpreting audiometric findings.

In the realm of speech and audiometry one very pressing research need is the establishment of the validity of the speech discrimination test. Alternate approaches to the assessment of speech discrimination such as multiple-choice tests and various types of sentence tests should also be explored. Finally, we must develop test procedures which explore discriminatory efficiency under difficult listening conditions, such as in the presence of competing messages, so as to be able to assess differential breakdown in understanding of speech when adverse acoustic conditions interact with hearing impairment.

8. Need for Improved Tests for Identification of Site of Conductive Lesion. The development and refinement of approaches to the assessment of sensori-neural acuity remains one of the most crucial research needs in audiology. Among the potential areas for investigation are the refinement of methodology for the objective calibration of bone-conduction transducers; the development of a truly standardized procedure for clinical bone-conduction audiometry which takes into account recent research findings relative to vibrator placement, peripheral masking, central masking, and the occlusion effect; and widespread evaluation of the acoustic impedance bridge as a supplement to or substitute for conventional bone-conduction audiometry.

9. Need for Improved Methods for Identification of Cochlear Impairment. A prime research need in this area is the definition of the common factor or factors underlying the various abnormal psychoacoustic characteristics attending cochlear disorders. Other, more specific areas of needed investigation are: further analysis of the aural overload phenomenon with particular reference to the extent of its effect on other test results; the clinical value of acoustic impedance measures as a means of assessing recruitment; the measurement of thresholds for short stimuli as a clue to abnormality in auditory integration time; the use of short stimuli at suprathreshold levels as a basis for binaural loudness balance testing for recruitment; and the use of frequency difference limen tests and threshold audiometry using frequency modulated tonal signals.

10. Need for Improved Methods for Identification of VIIIth Nerve Impairment. Among the

broader areas for research are explorations of the physiologic basis of abnormal threshold adaptation, the description of the earliest auditory VIIIth nerve involvement, and the widespread clinical evaluation of the effectiveness of the various test procedures which have already been described with the aim of defining a standardized clinical battery. Specific areas needing study include exploration of the decruitment phenomenon as a symptom of unilateral acoustic tumors and careful study of tone decay tests including systematic comparison with the result of Bekesy audiometry.

11. Need for Improved Methods for Identification of Central Neural Impairment. Fundamentally, the prime research needs in this area reflect our currently vague understanding of the neurophysical mechanisms underlying the processing of complex and transient auditory signals. Further work on the physiologic importance of the efferent auditory system and on means of evaluating that system is also essential. To date there has been no systematic effort to standardize and evaluate tests which presume to identify central neural impairment prior to clinical application. It is essential that a standardized test battery—based on current knowledge—be developed and subjected to widespread evaluation to determine clinical effectiveness. More specific topics for potential research are: the analysis of factors underlying failure of binaural fusion and binaural separation; the evaluation of the extent to which the averaged evoked response reflects CNS involvement; and the determination of the effects of well documented lesions at various levels of the CNS on the processing of acoustic signals such as those employed in the "distorted speech tests."

12. Need for Improved Methods for Identification of Pseudohypoacusis. The major research need in this area relates to the definition of a standardized test battery based on current knowledge and evaluation of its diagnostic accuracy. Since it is commonly suspected that a significant number of patients with pseudohypoacusis may go unrecognized in general clinic populations, some attention should also be directed to potential screening techniques which could be included in the routine test battery.

13. Need for Special Methods for the Identification of Hearing Loss in Infancy and Early Childhood. Currently, the most promising avenues of research can be defined in three directions. There is need for greatly intensified endeavor in the study of auditorially-evoked cortical response; this area may hold promise for several different aspects of diagnostic audiology. The currently fragmentary investigations in the area of the observation of various reflex activities such as the palpebral and acoustic reflexes and the use of cochlear microphonics as a means of assessing hearing in young children also show promise and deserve much more extensive study. Finally, methodologies of operant conditioning appear to have high potential when used with children not far removed from infancy.

14. Need for Improved Definition of Vestibular Function. Two broad areas of research needs can be defined. One relates to the development of approaches to vestibular testing that are more easily borne by the subject and more readily interpretable by the administrator. The other area is somewhat broader since it concerns the need for increased understanding of the neurophysiologic and pathologic phenomena assessed by these tests. Some of the topics which should be considered are the overall effects of the brain upon the end organ, the CNS events which occur in compensation for the total or partial loss of one end organ, the physiology of the saccule and utricle, and the patho-physiologic basis of postural vertigo, Meniere's disease and motion sickness.

15. Need for Clarification of Conductive Pathologies. Diseases of the middle ear are fairly well understood as clinical entities, and surgical techniques for correction of gross lesions are highly refined; but there is still room for progress in both these areas. There is great need for research into the in utero mechanisms producing congenital malformations of the external and middle ear structures, as well as into the genetic precursors and peculiarities of bone metabolism leading to otosclerosis. There is also much to learn about the physics of vibratory response associated with different pathological changes of the conductive system.

The same disease can produce different mechanical aberrations in different patients. The configuration of each patient's hearing loss is dependent upon the specifics of his mechanical aberration, as is the pattern and extent of restoration to his hearing that a particular treatment will bring him.

16. Need for Clarification of Cochlear Pathologies. The following illustrate the broad array of topics awaiting investigation.

a. Acoustic trauma. Although the effects of noise trauma on the animal ear have been fairly well described, it has not been actually established that similar effects occur in the human ear. Studies which have identified structural and citochemical changes in the cochlea should probably be replicated in human material before definitive conclusions may be drawn.

b. Ototoxic disorders. Several specific areas related to ototoxic drugs merit further investigation: the localization of site of action of the salicylates, the mechanism by which dihydrostreptomycin creates delayed hearing loss and the biochemical nature of the toxicity at the intracellular level. A great deal of investigation is also needed to further understanding of endogenous agents such as the toxins of bacteria of certain infectious diseases.

c. Infectious diseases. Research in the histopathology, prevention, and treatment of viral endolabyrinthitis is urgently needed. Correlative studies in cases of viral endolabyrinthitis of the histopathology and of special audiometric tests are unavailable. A wide variety of studies on the mechanisms of viral damage to the cochlea are needed. One specific research area which should be considered is the study of perilymph removed through a perforation of the footplate in patients with sudden hearing loss; careful biochemical and viral studies might reveal an etiologic agent.

d. Vascular disorders. As noted earlier, relatively little is known within this complex area. Therefore, research is needed in virtually all aspects of the area. As a relatively common clinical problem, Meniere's disease should receive priority as a focus for investigation.

e. Prenatal disorders. Additional new information on maternal viral infections and their effect on the fetus is needed. While the histopathological picture of maternal rubella is accumulating rapidly, many other viruses must also effect the fetal hearing organ and may be responsible for many of the congenital hearing losses termed sporadic hereditary hearing loss.

Much more information is also needed about the influence of teratogenic drugs. As the medical profession is constantly bombarded by a whole spectrum of medications, advocated by the pharmaceutical houses for all conceivable ailments, there is continuing need for careful study of the effects of certain drugs on the developing embryo.

f. Congenital hereditary disorders. Audiologic and otologic clinic research programs should proceed hand-in-hand with studies in metabolism, biochemistry, and cytogenetics. One specific area for concern is the complete lack of information about the morbid anatomy of progressive heredodegenerative sensori-neural hypoacusis.

g. Delayed hereditary disorders. Two specific topics for research relate to the two conditions mentioned previously. A very interesting area for study concerns the congenital luetic at the time of onset of ear symptoms. Fluid from the inner ear could be studied to determine the presence of spirochetes. If present, it should be determined whether penicillin or one of its derivatives can be introduced into the inner ear at therapeutic levels.

Atrophy of the stria vascularis is of particular interest in that the hearing impairment is probably due to a biochemical or enzymatic disturbance, without morphological change of the sensori-neural system. Thus, given a normal mechanoreceptor and neural system, there exists the possibility of replacement therapy.

h. Neonatal disorders. Most of the information we have about the pathology of kernicterus, anoxia, and hypoxia concerns the central nervous system; little is known about the morphological changes within the cochlea. It would, for example, be interesting to acquire human temporal bones from patients who have suffered hyperbilirubinemia to describe the peripheral changes which are presumed to accompany this disorder. It is also possible that animal experiments could be performed in which hyperbilirubinemia deafness is produced and the pathological changes identified.

i. Cochlear otosclerosis. While the histopathology of otosclerosis, its structural changes, sensory aspects and audiometric manifestations have been described, the etiology is still obscure and the modus of inheritance has not been clearly established. Many questions also remain regarding the sensori-neural component which so frequently accompanies this disease. Continuing studies involving the correlation of functional tests with histopathological findings should be supported.

j. Temporal bone trauma. Probably the most productive research relating to temporal bone trauma should lie in the area of prevention. Automobile accidents are clearly the most frequent causes of such injuries, consequently continuing research in safety features in automobiles—including, perhaps, the use of safety helmets—should be encouraged. In addition to this border area, it should also be observed that while the morphological alterations caused by the different fractures involving the temporal bone are fairly well understood, insufficient information is available about blunt injuries with concussion of the cochlea and labyrinth.

k. Presbycusis. As noted earlier, relatively little is known about the essential pathology of the condition or conditions which are commonly designated under the rubric "presbycusis." Additional correlative studies of special audiometric tests with pathological findings in both the peripheral and central auditory pathways are needed to increase our understanding of the various types of presbycusis.

17. Need for Clarification of Disorders of the VIIIth Nerve. There is almost no experimental work which relates, under controlled conditions in animals, the audiometric findings with VIIIth nerve lesions. There are many phenomena observed concerned with abnormal adaptation of the VIIIth nerve to a sound stimulus when there is a lesion of this nerve. These concepts need objective physiological explanation. It would be of great use, in the next decade, if some laboratories were to investigate in animals the

types of lesions needed to obtain these differences in adaptation. Much of the basic work concerning single unit activity of the VIIIth nerve has been done and the time is propitious for applying this information to clinical problems.

a. Infectious diseases. Further research into virtually every aspect of the presumed condition of neuritis of the VIIIth nerve should be encouraged. As noted earlier, virtually nothing is known about the exact nature of the disease, if, indeed, such a specific disease entity exists.

b. VIIIth nerve tumors. Much more study is needed to determine the etiology of tumors of the VIIIth nerve. Additional research into surgical techniques for treatment is also indicated. Although not ordinarily considered an essential problem for research, much more effort is needed to increase the awareness of all physicians—including otologists—of the need for considering the possibility that a patient with a unilateral hearing and/or vestibular disturbance may have an VIIIth nerve tumor and obtaining appropriate special diagnostic studies.

c. VIIIth nerve degeneration. Studies are needed to determine the factors involved in premature cell death of the VIIIth nerve. The problem lies in the field of cell biology and would probably be best studied with techniques of organ and tissue culture. Before rational therapy can be applied we need knowledge as to what factors cause the cells of the VIIIth nerve to degenerate, i.e., to undergo premature cell death.

18. Need for Clarification of Disorders of the Central Auditory Nervous System. Research needs in this area are illustrated by the following three examples.

a. The continued refinement of clinical testing methods, especially those directed toward an elucidation and evaluation of the basic elements of the auditory process.

b. Clinical pathological correlations in which efforts are directed toward relating specific deficits in the auditory processes to specific brain lesions in the human.

c. Exploitation of the new psychophysiological methods in animals, involving the use of conditioning techniques to elicit a response accompanied by the use of microelectrodes and computer averaging techniques to evaluate the observed responses in the central nervous system.

19. Need for Clarification of Pseudohypoacusis. We have come to presume that the audiological identification of pseudohypoacusis is relatively easy. However, very little is known about the genesis and mechanisms of pseudohypoacusis. We have particularly limited insight into psychogenic hearing impairments whose possessors are not aware that simulation is occurring. It is insufficient merely to consider such conditions as symptoms of psycho-pathology without concern for whether they have distinctive dynamics. Appropriate study may well reveal unconscious pseudohypoacusis to be more prevalent in some clinical populations than we have supposed. It may also reveal that there are times when the professional postures of audiology and of otology tend to solidify psychogenic hearing defects. Finally, and here we are looking at the reverse side of the coin, there may be auditory disorders resulting from certain CNS lesions which have symptomatology paralleling pseudohypoacusis closely enough so that we are in danger of classifying such symptomatology as simulated. Such an error could not help but lead to faulty management of the patient.

20. Summary. Great strides have been made in the understanding of auditory disease and hearing problems. However, research in every aspect of this broad clinical area can be considered as only barely begun. Auditory pathologies and hearing disorders require much more definitive description. Their psycho acoustic aberrations must be clarified. Tests for their diagnosis need many refinements. Methods for their treatment await extensive delineation.

D. *Training Needs*. Three major types of research workers are required to investigate needs of the kinds just outlined. Each type has a unique contribution to make to the study of pathology of the auditory system in relation to hearing. First, there is the research otologist. Then we have the interdisciplinary scientist willing to focus on auditory problems and aberrations. Lastly, there is the research audiologist.

Research otology has outlets for many specialists. There is great opportunity for basic research in such areas as histopathology, electron microscopy, and otologic physics. The area of otoneurology is just evolving to the point where it can learn to combine effectively auditory and vestibular findings with sophistication. Finally, clinical problems offer a vast array of outlets to the researcher oriented toward clarifying auditory diseases and refining treatment for them.

Interdisciplinary investigators committed to using their skills for the study of hearing are sorely needed. Consider for example, the contributions to be made in genetic otology, in geriatric otology or in otoradiology. Or contemplate the array of biochemical and biopathological questions awaiting answer. These range from clarification of the mechanisms of otosclerosis or of the mechanisms whereby ototoxic drugs damage cochlear structures to explanation of the manner in which some prenatal viral infections ravage the auditory system. Or, again, think of the investigations which require the insights of the pediatrician, of the child psychologist, of the neurologist or of the neurosurgeon.

Audiologists can bring their own unique focus to bear on the study of auditory diseases and disorders. These scientists focus on two major types of problem: 1) the study of hearing behavior as a means for developing refined tools for differential diagnosis among auditory aberrations and 2) the investigation of disturbances in auditory capacity as these interfere with communicative efficiency. To these ends the audiologist may be concerned with basic psychoacoustical behavior as exhibited by different clinical types. He may concentrate in the area of paedoaudiology and the diverse testing techniques required there. He may delve into the more practical applications of clinical psychoacoustics, or he may focus on the communicative requirements and capacities of the various categories of hearing impaired.

Unfortunately, there is an extremely limited supply of researchers of the kinds just described. Firm statistics are here also notable by their absence. No one can tabulate the interdisciplinary investigators with prime commitments to clinically oriented hearing problems, but their number in this country cannot exceed 50. The number of audiologists devoting most of their time to research can not be any greater. The dearth of research otologists can be somewhat more precisely documented and hence stands as a clearer example of the slimness of the attack through research on pathology of the auditory system.

According to statistics compiled by NINDS from various sources, there were 300,386 physicians in this country in 1967. About 2.1 percent (6,295) of these individuals were otolaryngologists. Interestingly, only 60.3 percent of all physicians were in private practice; but this ratio rose to 90.1 percent among otolaryngologists. Moreover, 10.3 percent of the larger group, but only 2.6 percent of the otolaryngologists held full-time hospital appointments. Even more pertinent for us is the fact that, while 4.7 percent of all physicians held full-time teaching and research appointments, the ratio of otolarygologists so employed was only 1.9 percent. This last figure becomes more startling when one realizes that it represents a total of merely 121 teachers and researchers for the entire field of otolaryngology. When one remembers that this number thus included laryngologists as well as otologists and that some were full-time clinical teachers, not more than 60 individuals can be said to be otologists with anything approaching a full-time commitment to research.

The foregoing resume leads directly to the conclusion that we require a substantial increase in research otologists, interdisciplinary but otologically oriented scientists, and research audiologists. This increase can come only through the support of training programs which will attract superior young minds to make their professional commitments in these areas. Some such programs exist; but more are needed and all must be given adequate support. The alternative will be a perpetuation of the present situation, wherein research personnel in these areas are in much lower ratio than is even average among the medical sciences.

IV. EDUCATIONAL AND REHABILITATIVE MANAGEMENT OF AUDITORY DISORDERS

A. *Status of Contemporary Knowledge.* The Subcommittee recognized that the topic of educational and rehabilitational management of auditory disorders is, in fact, many topics, because communicative capacities and communicative deficits vary radically with age at onset of hearing impairment, degree of loss, past educational and rehabilitative management, and socio-economic circumstance. This situation is the crux of the discussion which constitutes the remainder of this chapter. Often, in this discussion, the Subcommittee has felt that it could best present the points at issue by quoting statements from the resumés of selected areas which a number of consultants in education and rehabilitation prepared for the Subcommittee's guidance. (These statements are in the Subcommittee's files but are not reproduced in toto as part of the Subcommittee's report.)

Dr. Stephen P. Quigley emphasized for us the diversity of issues when he divided the acoustically handicapped population into 24 categories based on the interactions between the age of onset of loss and the degree of impairment. He rightly stressed that adjacent categories often involve substantial overlap. Nonetheless, his matrix of categories illustrates the scope of problems facing educators and clinicians. The child who has suffered more than 90 dB of impairment prior to the age of two poses a completely different socio-educational challenge than does the oldster with only a mild loss that became bothersome after age sixty.

The discussion which follows does not consider each of Dr. Quigley's categories separately, but it does recognize major distinctions based on age of onset and degree of impairment. This discussion starts by reviewing contemporary knowledge as to the management of deaf children.

Deaf children were recognized over a century ago as a handicapped group requiring special education. Their management was based on the "art" of teaching such children as this "art" first developed in Europe and then underwent modification in this country. Deep controversies regarding teaching techniques arose, but incisive research to resolve these controversies was not undertaken. True, by the

1920's, educational psychologists had become alert to the field of education of the deaf. They initiated studies on the intelligence, the educational achievement, the language skills, the performance levels and other aspects of the deaf population. A few psychological tests were actually developed for use with the deaf. This line of research has been refined and extended during the intervening years. Consequently, we now possess a fairly substantial volume of quantitative information on that portion of our deaf population that is encompassed in our educational system, and a few studies of deep sophistication have been performed.

By contrast, both hard of hearing children and acoustically impaired adults have been largely ignored as research populations. These individuals are not easily perceived as comprising cohesive subgroupings, nor have their needs had as high priority in American social conscience. To be sure, the last few decades have seen establishment in regular schools of many classes for the hard of hearing children, and such children have in some instances been enrolled in sizeable proportion in special schools for the deaf. Likewise, rehabilitational facilities for adults have become increasingly numerous during the past 20 years. Both trends, however, have been characterized by empirical expediency. The "art" of coping with practical problems has taken precedence over rigorous investigations to discover improved methods of educational and rehabilitative management. Even today, research directed toward this goal is a rarity.

In summary, we find ourselves in the situation of having some types of research knowledge on deaf children but of lacking not only other types of knowledge of the deaf, but also almost any research information on either hard of hearing children or acoustically impaired adults. Bearing this circumstance in mind, we turn now to a more detailed resume of contemporary knowledge.

1. Management of Educationally and Socially Deaf Children. The first channel of attack in the management of such children is through parental guidance. Most children with drastic hearing impairments are discovered rather quickly, which means that in many instances the child is still so young that his special training must be carried on at home; and, in any event, many of his major adjustments must be in the home. There has been a great increase in facilities of guidance for parents of deaf children, and many training programs for them have been established. Confusion, however, is rampant. Dr. S. Richard Silverman described the situation for us thus:

> There appear to be no universally accepted specific aims or procedures in guiding parents of very young children. For some, the primary aim is to create realistic "acceptance" of the child's condition, and counseling is weighted toward psychotherapy.
>
> For others, the emphasis is toward conveying information in order to create an understanding of sensory deprivation and its effects on the total development of the child in general and his communication deficit in particular.
>
> Such evidence that exists for the value of particular procedures and programs of parent counseling is meager and is generally anecdotal or based on studies (frequently retroactive) of children's records. Indirect evidence from neurophysiology is accumulating to suggest critical periods in the . . . plasticity of the nervous system and the influence on its development of sensory experience. Psycholinguists, too, point to a critical optimum period for the acquisition of language, particularly its syntactic features.
>
> Most significant for parents seeking guidance is the long range outlook for the child. This too reflects the general views of the counselor about deaf persons. These views are often determined by the guider's value system, by his own experience with the school and post-school adjustment of deaf persons, by his own professional training and indoctrination, by his relation to a deaf person or some combination of these.

One may conclude that we have no solid base of research data on which to decide the guidance of parents of deaf children and that professional opinions differ widely enough so that the alternatives in guidance posed for parents are bewildering to them.

Formal management of deaf children concentrates largely on their educational programs. Dr. Edgar L. Lowell told us regarding such programs:

> The accomplishments in this area were summarized by the Secretary of Health, Education and Welfare Advisory Committee on the Education of the Deaf which showed that deaf children are seriously educationally retarded regardless of the method of training employed. Those findings were corroborated by several other independent studies. We may be drawing erroneous conclusions from these findings, however, for two reasons. We are probably losing the more able deaf students because they move out of the traditional deaf education pattern and attend hearing schools. . . . We are probably also including in our statistics a great number of children who suffer from some other type of subtle or not so subtle central nervous involvement . . . (but) . . . I do not think such contamination would entirely account for the present situation. Particular effort would

> appear to be needed to close this educational gap.

On this same topic, Dr. Silverman commented:

> The time-honored approach to the psychological and educational assessment of deaf children has been to compare their performance with that of hearing children in tests designed for the latter. Evaluation of intelligence, motor ability, social maturity, personality, and perceptual skills have generally followed this pattern. Fortunately, the diffuse and indiscriminate use of such tests is yielding to more sharply focused testing. . . . For example, we are increasingly concerned with the nature of deafness itself and its effect on the total outlook and behavior of the child and not merely as a cause of inability to communicate verbally. We are interested in the visual perception of deaf children not only because most of them are likely to receive a major portion of information about the external world by this means, but because deprivation of auditory perception may affect visual perception . . . we recognize the need for relating the performance of our deaf children to that of their hearing peers. Nevertheless, the conventional tests do not describe adequately language and language related aptitudes, skills and problems of the children.

A primary goal in education of deaf children is the development of their language. Dr. Lowell commented:

> Our knowledge of language development in normally hearing children is just beginning to develop through the interests and efforts of the linguists. The implications of their findings for the education of the deaf have not yet been demonstrated but offer a fruitful area of progress in the near future.

Dr. Silverman added the thought:

> We know how fundamental language is for hearing impaired children. Essential for an improved understanding of how it is learned and consequently of how it should be taught is a satisfactory description of language. Investigators and teachers have sought diligently for descriptions and measures beyond those yielded by standard tests . . . They have used such measures as sentence length and complexity, frequency of occurrence of certain parts of speech and word orders, extent of vocabulary, type-token ratios, subordination, and abstractions. They have used the methods of structural linguistics to analyze the functional and lexical features of the spoken and written language of deaf children. This is one of many possible leads to better description of language and to improved techniques of teaching . . . not to mention the subtle and little understood interweaving of the learning of language and the formation of concepts.
>
> In general, the tasks presented to deaf children in studies of their abilities to "conceptualize" . . . have been quite simple and higher mental processes seem not to have been investigated. Throughout there is an assumption that verbal performance is equated with linguistic competence but it is reasonable to suggest that sign or gesture although not verbal may have linguistic attributes.

Deaf children must, of course, have special training if they are to achieve a communication system that will serve them socially. The two basic methods are the manual (which employs the "give and take" of a gesture language) and the oral (which calls for the child to speak and to understand others by lipreading); and, of course, the two methods may be combined. Dr. Lowell made the obvious comment that little has been done to resolve the traditional controversy between these methods, particularly as they are used as vehicles for education.

In any event, a reasonable goal is to give each deaf child as intelligible speech as possible for, as Dr. Lowell said:

> Any of our other accomplishments in improving the education of the deaf would be jeopardized by a graduate who is only able to communicate with those who understand manual communication.

As regards educational methodology in speech training, Dr. Silverman remarked:

> For some educators speech is a subject to be taught like a foreign language to those who can "benefit" from it . . . . For others, speech is a basic means of communication and hence is a vital mechanism for adjustment to the communicating world around the child.

As regards research methods for refining speech training he says:

> Students of speech of deaf children have been greatly stimulated by the development of improved tools and methods for the investigation of speech as an acoustic event. We now have techniques for analyzing and synthesizing speech, for making it available for visible and tactual display and for re-packaging it by selective filtering, frequency transposition and temporal expansion, and contraction. These should aid our analysis of the perceptual features of speech and guide us in its appropriate manipulation for the benefit of the speech development of children whose range of the perceptual cues of speech are severely limited.

Dr. Silverman added the following points of importance:

> The search has gone on vigorously for an orthographic system as an aid to teaching that would carry information about speech unambiguously and would at the same time be perceptually simple. And the fundamental unit—phoneme, syllable, word or phrase—most suitable for the structural teaching of speech is a subject of great interest.
>
> By evaluation of speech, we mean not just its intelligibility, but its practical, long-range, social usefulness. We have come to learn that intelligibility and social usefulness are not linearly related. Attitudes of talker and listener having to do with confidence, encouragement, frustration, motivation—all play their role in the use a deaf person makes of his speech.

The deaf child's reception of speech from others must be through lipreading (often called speech reading) plus whatever limited auditory clues he may find useful. Lowell described the linguistic substratum requisite to lipreading thus:

> The complex perceptual task of lipreading depends in a large part on the way the individual has the contingency relationships in speech stored and available for immediate recall . . . . Since we are only beginning to understand the processes whereby the normal hearing person builds up these internal contingency tables, it is not surprising that we are lagging far behind in their application to the problems of the deaf.

Regarding current knowledge on lipreading, Dr. Silverman summarized:

> . . . we find that we can make rather reliable judgments about who is a good, bad, or indifferent speech reader. Ingenious attempts have been made to relate intelligence, educational achievement, hearing loss, time of onset of deafness, linguistic and perceptual skills, and personality to these judgments. Although there are promising leads here and there and the value of speech reading as a complementary element in bisensory communication has been demonstrated, the failure of a clear pattern of relationships continues to frustrate.

There is relatively common agreement that deaf children with some residual hearing should receive auditory stimulation. As Dr. Silverman put the issue:

> The importance of early auditory experience is now recognized . . . The extent to which auditory stimulation is combined with specific modes of visual communication such as lip reading, gesture and even finger spelling varies and is the subject of much critical discussion. A deliberate unisensory approach—visual, auditory or even tactual versus a bisensory input—audio-visual, audio-tactile, visual-tactile—and the precise components thereof is a pervasive question in the education of deaf children at all ages.

Dr. Lowell said of the unisensory approach:

> To the best of my knowledge, we have no definitive results on the relative merits of this approach. The Russian literature on intersensory inhibition may provide helpful leads for future research.

A topic of great current interest is utilization of a child's residual low-frequency hearing by transposing at least part of speech electronically into this frequency range. Dr. Silverman pointed out that for many children this listening task requires a new language to be learned; while Dr. Lowell remarked:

> The current research on frequency transposition may demonstrate that this offers a solution to the amplification problems of the deaf, but the evidence is not yet available. One can not help but wonder how much of low frequency "hearing" is not of cochlear origin.

Another major area of concern, although it is ordinarily handled through formalized school facilities, is the vocational training of deaf children. Here meaningful research is almost non-existent. Dr. Silverman described the problem impellingly for us, and thus indirectly emphasized the lack of substantive data from which to proceed, when he said:

> Economic well-being is an essential ingredient of individual and social self-realization. Of growing concern is the increasing number of young people between the ages of 17 and 22 who enter the labor market without any marketable skills or with skills that, at best, are marginal.
>
> Education of the deaf cannot ignore this distressing situation, since realism compels us to recognize that in any economy our students may find their economic opportunities limited . . . . The old panacea, "Give them vocational training," will no longer do. Vocational training for what? Educators are faced with the perplexing problem of preparing young people for jobs that at the time of their schooling do not yet exist. Furthermore, specific vocations for which they are being educated may cease to exist when the students graduate or after they have been employed for a discouragingly short time.
>
> Final and complete solutions are not yet in sight, but one principle is becoming increasingly clear. We must equip young people with those fundamental skills that enable them to acquire new skills when the situation demands that they do so. They must be prepared to accommodate to change.

> We need to minimize the obstacle of inferior communication that may block the path to vocational success. Experience is suggesting that we must extend the period of time over which we stress such skills as reading, language usage, and mathematics, and not replace them with premature and poorly conceived 'vocational training.'
>
> The establishment of the federally sponsored National Technical Institute for the Deaf . . . should be exploited as an interesting laboratory for the study of the preparation of deaf persons for economic independence.

In conclusion, it is clear that the management of educationally and socially deaf children has proceeded and is now conducted primarily in terms of academic preconception as to what are preferred techniques. These preferred techniques have been defined in terms of qualitative judgments based on non-systematic observation and in terms of an "art of teaching" that has evolved among educators of the deaf in consequence of many decades of work with this particular kind of handicap. Let no one mistake, great credit is due to the dedicated people who have evolved this 'art,' and the human good they have done is inestimable. However, this area is one which is only beginning 1) to develop a research approach of its own, 2) to envision problems on topics and with techniques that depart from the traditional and 3) to draw into collaboration the diverse discipline which when focused through research on the management needs of the deaf can supply definitive insight instead of supposition.

2. Management of Educationally and Socially Deaf Adults. Special management of the adult deaf requires attention in five distinct areas: guidance, special education, vocational training, social experience, and emotional adjustment.

Knowledge of how best to proceed to help the adult deaf is relatively limited and the number of professional workers skilled in these areas is small.

Dr. Arthur I. Neyhus remarked for our Subcommittee:

> Guidance for the hearing impaired implies the process of helping those with hearing losses from early life to make maximum use of their abilities and potential . . . Such is not the case with the adult deaf today . . . many are employed in occupations that are below what they are actually capable of performing . . . and there is an unnecessary delay in preparing the deaf young adult for the working world. Before improving the guidance service for the deaf there is need to understand further the adjustment of the deaf in the hearing world . . . Hence a survey of the position of the adult deaf in the hearing world would provide the necessary information around which proper guidance programs can be built.

Dr. D. Robert Frisina commented especially to us on the group of educationally and socially deaf whose deafness occurred after language and speech acquisition (onset age of six years or later). These individuals represent about one fifth of the total deaf community. They constitute a relatively small population who are widely dispersed geographically so that data on them are hard to obtain. Dr. Frisina said that their

> . . . essential counseling needs relate to the interrelationship among communication, hearing aids, occupational goals, and personal and social adjustment. Systematic studies of these interrelated functions with this subgroup of deaf persons are non-existent.
>
> For the most part counseling with members of this subgroup . . . (has been based on) extensions of existing theories and practices derived from hearing persons . . . . There is a growing awareness that the rehabilitation processes involve more than counseling the individual with the handicap; further involvement with the significant people in his environment is becoming increasingly apparent.

Dr. Neyhus pointed out that:

> Further efforts in the guidance area are needed in the developing of training programs for the guidance worker, the demonstration of the value of a complete guidance program in the schools for the deaf, and the development of techniques for guidance specifically for the deaf.

Turning to the question of special educational help, Dr. Neyhus added:

> Many deaf young adults and older adults seek the assistance of schools and clinics for the improvement of communication skills and language abilities . . . . Further study is needed to determine whether there are methods beyond those presently used that can improve the oral communication skills of those basically manual, to determine whether it is feasible to contemplate such a program of 're-education.' We must also seek methods that can help the adult deaf improve their present fifth grade level of academic achievement . . . . Although some attempt has been made at 'adult education' for the deaf, further study is needed to develop programs of study to make up for the present lacks in the typical education of the deaf.

Dr. Frisina discussed refresher training for the adult deaf whose impairment occurred after language and speech acquisition. Middle ear surgery and wearable hearing aids have reduced the heavy reliance such individuals previously had to place on lip reading; and Dr. Frisina feels that

> More critical appraisal of the role and approach to lip reading in a case requiring rehabilitation is necessary than perhaps before when utilization of residual hearing was less likely . . . . Refresher training in speech is of low priority for this group. Faulty speech patterns do exist but as a rule do not render speech unintelligible.

The National Technical Institute for the Deaf which has so recently begun its operation will of course have a great impact in this realm of vocational training. However, there is danger that it, like Gallaudet College, will tend to serve the superior deaf adult. Strong attention, probably much of it through the National Technical Institute for the Deaf, will continue to need to be given to the requirements of the person who, quite aside from his auditory handicaps, has only average or below average mental endowment. As Dr. Neyhus put it:

> . . . the average deaf adult who will be entering the working world will be working with his hands, usually in a job requiring some skill. Further information is needed regarding the job market and, especially, of the type job that can be performed by the deaf; also needed are instruments that can assist in evaluating the deaf adult to determine his interests and aptitudes.

Dr. Frisina commented that needs of vocational assistance tend to rank second to counselling needs for adults whose deafness follows speech and language acquisition:

> The vocational assistance required by the deaf subgroup being discussed required initial evaluation of potential and generally results in one of three alternatives. The first alternative is . . . the development of a marketable skill wherein one did not exist previously. The second alternative is up-grading or rehabilitating of a once marketable skill which has been threatened by traumatic deafness. The third alternative is one of retraining for a new occupation because the deafness has precluded the continuation of an existing vocational skill or competence.

Regarding social experiences, Dr. Neyhus said:

> The social immaturity of the deaf has been well documented. Although there is a well organized social program for the adult deaf developed by the deaf themselves, it appears limited in the satisfactions that it provides its participants; experience has also indicated that these programs tend more to isolate the deaf rather than provide them with the opportunities of improving their social abilities. Here also is a fertile field for research to determine the manner in which the deaf can improve their capacity for self-care, for the care of others, and for developing a better awareness of their role in . . . the community on the same level as the normal hearing.

Data regarding the effects on social functioning which arise when deafness follows speech and language acquisition are largely anecdotal. Dr. Frisina commented that studies indicate that such individuals tend not to be included in the deaf community. He said, "It is assumed, therefore, that with varying degrees of success, they are being assimilated into the mainstream of the general population." However this view may be biased by the fact that it is derived largely from the college population of deaf individuals and this population represents only about 8 percent of any single age group among deaf persons.

Finally, Dr. Frisina stated for us,

> Much information has been learned concerning the personality of the adult deaf. However, there is need for the development of test procedures and instruments that will help in the evaluation and identification of behavior disorders. There is also need for the training of personnel in this area as well as the development of therapeutic techniques that will aid the therapist in dealing with this problem.

In conclusion, the limitations in our current research knowledge on management of deaf children are even more apparent in our approach to the deaf adult. It can be seen that even more than in the realm of work with children, the field of managing the adult deaf is only beginning 1) to develop a research approach of its own, 2) to envision problems on topics and with techniques that depart from the traditional and 3) to draw into collaboration the diverse disciplines needed to insure broad and viable research on the adult deaf.

3. Management of the Hard of Hearing Child. The hard of hearing child is the youngster who has sufficient hearing impairment to suffer educational and social handicap yet whose hearing is good enough so that it may be used as a major communication channel. Most such children have hearing losses that do not average more than about 65-70 dB when classified in terms of degree of threshold deficit. Of course, such children may also possess added deficits in supra-threshold auditory capacity which are not revealed by threshold measurements. However, whatever the details of each such child's impairment, the feature which separates him from the deaf is that he can employ the auditory sensory modality as an input of major significance. This fact means that such a child has a very different set of experiences and presents very different problems of management than does a deaf child (recognizing, of course, that there are children whose hearing disorders place them on the borderline between the two categories).

Research during the past three decades on the management of hard of hearing children has centered very largely on two topics: on case finding and on determination of the degree of impairment.

Soon after the invention of the pure tone audiometer, large programs designed to identify the hard of hearing children in our school population were launched. The most notable impetus to this movement came from the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology, but many groups and individuals conducted studies on the efficacy of various methods for screening school populations. The ostensible impetus in many of these programs was to find children with minimal and (hopefully) reversible impairments who could benefit from otolaryngological treatment. Here the goal was primarily preventive, since it was assumed that many such children, if untreated, would develop permanently handicapping deficits. However, such programs were frankly aimed also at discovering youngsters requiring special educational management. It is fair to say that research on screening audiometry has proceeded to the point where the remaining problems are largely tactical. We have the tools for case finding. The question now is how best to use them. Consider the fact that the recent Pittsburgh study revealed many children whose hearing was normal yet who exhibited ear pathology requiring treatment. In the face of such a finding, the use of audiometric testing as the primary screen for isolation of children with ear disease becomes suspect, even though its value in finding the educationally needy cases remains.

The same conclusion, at a much more sophisticated level and without implying that definitive answers are in, can be said of research on methods for quantifying hearing impairment. Here two types of problems have presented themselves. The first has been the task of developing techniques for differential diagnosis that would separate hearing impairment from such other conditions as mental retardation, perceptual problems due to CNS lesions or psychological difficulties. Some effective clinical procedures have developed out of observational and other types of research on this question. Thus, one facet of the search for reliable methods of differential diagnosis has been the development of highly sophisticated techniques, such as electroencephalographic audiometry, that seek to ascertain whether auditory response is occurring normally. Such research is currently vigorous and holds promise of high productivity. One of its goals, and this gets into the second type of problem, has been to obtain a reasonably well quantified measure of a child's auditory performance. Techniques designed to accomplish this goal have varied from use of toy noise makers and of filtered versions of ordinary sounds to measurement of electrodermal response, electroencephalographic pattern, etc. The end result of investigating the value of such methods has been that clinicians have been given a variety of tools which, when used with sophistication, allow reasonable estimates of a child's residual hearing to be obtained quite early in his life.

Another research development of significance is the perfecting, in connection with the NINDS Perinatal Study, of very simple "screening" tests which can be used by nurses, etc., to help identify high risk cases very early in life. These simple tests help "red flag" the infant who may either have a hearing problem or may have some other difficulty.

We are in a research desert the moment we leave the realm either of finding hard of hearing children or of quantifying their hearing deficits.

Strong but conflicting traditions as to how to manage hard of hearing children educationally and socially have evolved 1) from "common sense," 2) from extrapolation of the experiences of hard of hearing adults and 3) from the implications of research on psychological and linguistic performances of normal hearing children. Each viewpoint has its zealous advocates. These traditions are incorporated in the educational practices of school systems that accept hard of hearing children. These traditions have become embodied in the procedures of audiological clinics and other types of guidance centers. But on the whole, these traditions lack either confirmation or refutation through research.

Another disturbing feature is that the limited insights we have frequently are focused on the hard of hearing child too late in his life. As Dr. Miriam Hardy has put it for our Subcommittee:

> By and large, in terms of his potential, and what can be done to alleviate sensory deprivation and to close the language gap, the hard of hearing child has been one of the most neglected of our children. All too often he is not identified until he has met with school failure, often thought to be stupid, and seldom receives the help he needs to enable him to keep up with his hearing peers. All too often, even when identified, there are not adequate facilities for his needs. He is either buried in a group of deaf children, or left to struggle without adequate supportive help in the regular educational stream.
>
> The crux of the problem of the hearing impaired child is the effect of sensory deprivation in the acquisition of a language need. The handicap is not really measured in 'decibels' but is more appropriately described in terms of 'linguistic age,' and the child's ability to function reflexively in any language situation.

There is an appalling dearth of solid facts on incidence, etiology, and kinds and degrees of hearing loss associated with these etiologies. We lack documented, longitudinal data on such factors as the following:

1. The reliability and validity of early auditory tests on infants and young children (EDR, EEG, etc.) as compared with later standardized test procedures.
2. The stability of auditory function; i.e., the incidence of degenerative processes and with what etiologies.
3. The causes of delayed auditory response in infants, who act as if they do not hear, and who later demonstrate no loss in auditory sensitivity.
4. Kinds of breakdown in function that suggest interferences in the central auditory and integrative systems.
5. The auditory configurations that can be compensated for by amplification so the child can learn to understand through hearing alone, or with what a combination of listening and looking . . .
6. The kind, shape and depth of loss associated with known specific etiologies, or unknown etiologies.
7. The effectiveness of currently available commercial hearing aids to compensate for specific types of hearing problems.
8. The kinds of amplification that have demonstrated their effectiveness for a particular age and type of loss.
9. The growth and maturation of the child's ability to use his residual hearing after the introduction of appropriate amplification. What kind of training?
10. Developmental linguistic norms for language acquisition against which to compare the current status of a child and to plot the growth of his language facility in all modalities over time.
11. Intelligibility of speech and the factors that account for it.
12. The incidence and kinds of other involvements to compound the hearing impairment.
13. The effect of intelligence on the habilitative processes.
14. The habilitative and educational program pursued.
15. The academic achievement record and level of scholastic attainment.
16. The vocational program, the kinds of occupations followed and the evaluation of their appropriateness.
17. Kinds of parental guidance and parental factors that seem to influence success or failure in the child.

In conclusion, hard of hearing children stand as a population whose needs and potentials are essentially unknown. These children, unlike their deaf brethren, have not been the object of long-term social concern. Hence, they have not been clearly identified nor made the object of a zealous analytical and educational endeavor. Whatever "art" has developed in their management has been sporadic and uncertain. To quote Dr. Hardy:

> A kind of litany is employed—"hearing aid, auditory training, speech and lipreading, language stimulation and training, and parental counseling." All too often these steps are carried out as discrete, loosely related endeavors with limited appreciation of their fundamental interrelationships, much less developed into a a carefully programmed sequence designed to make language in all modalities a reflexive tool for the child.

Small wonder research in this area has been so sparse. The social conscience has been lethargic. It must come alive first. Once it is awakened, vigorous research must be a first order of business if proper programs for managing hard of hearing children are to be achieved in minimum time.

4. Management of Hard of Hearing Adults. Dr. Quigley reported to the Subcommittee:

> An extensive survey of the literature reveals that data on management of the hard of hearing in general are limited. Most studies are concerned with etiology and diagnosis rather than management. Within the literature on management which does exist, it is impossible to determine how much of it is concerned with those adults who suffered impairment of hearing before language and speech were acquired. This distinction on the basis of age at onset is not made in most studies of the hard of hearing adult. This situation is distinct from that of individuals who are classified as deaf . . . . It is likely, though this cannot be substantiated in the literature, that the pre-lingually hard of hearing adult might also have more severe problems in language, speech, educational achievement, and other areas than those who are post-lingually hard of hearing.

Dr. John J. O'Neill said in discussion of this same topic that "there is a need for a rather comprehensive study of the effects of early hearing loss upon the speech and language development as well as the effects it has upon perception, cognition and the individual's emotional approaches to the world." In other words, since no definitive information is available as to the impact of early hearing loss on acquisition of his communicative skills, we have no basis for judging in what manner our management of the hard of hearing adult should be conditioned not only by such factors as the severity of his impairment but also by the time of its appearance.

One reason for failure to dichotomize the adult hard of hearing population on the basis of onset of loss is that by the time a person reaches adolescence the competency level of his major linguistic skills is established and the problems of management are primarily those of maintaining these existent skills. Thus, the thirty-year-old whose moderate hearing loss has been static since early childhood has achieved an adjustment that he and his intimates accept. His habilitational management and special educational training are long past. If he wears a hearing aid he is accustomed to the potentials and limitations it holds for him. So long as a new crisis does not arise, he feels no need to seek professional help except possibly an occasional refresher regime of lip reading or speech instruction. Such an individual does not pose the same kind of clinical challenge as does the more recently handicapped person. This latter person has a recollection of the efficiencies he has lost and is a candidate for substantial rehabilitation instead of modest additional habilitation. Hence, management of the hard of hearing has essentially ignored age of onset. It has assumed that comparable procedures are to be employed whenever clinical tasks have surface similarity. For example, differences in procedure because of age of onset are not usually considered important when a clinician is dealing with seasoned hearing aid users who are merely seeking help in selection of a new instrument to replace an old one.

Recent research on lip reading has been limited, but this topic has been subjected to enough study over the years so that, in Dr.O'Neill's words,

> Research . . . indicates that there is no definite relationship between lipreading ability and intelligence. Also, there does not appear to be any possible relationship between lipreading skill and certain personality and behavioral factors or visual skill. However, the characteristics of the speaker or sender appear to have some effect upon lipreading, as does the nature of the lipreading stimulus. Experimental study has also indicated that vision does assist in the understanding of aurally presented material.

The area that has seen the most attention is that of hearing aids and their use. This topic has attracted sporadic investigations ever since the intensive emphasis it received during World War II, and by now a substantial literature has accumulated. However, much of the research on hearing aids has been superficial—centering on such questions as the value of particular methods for hearing selection without adequate concern for incisive validation of these methods. Two tendencies are to be noted in this research. For one thing, some investigators have had relatively strong preconceptions and their experimental designs have not been sufficiently definitive to put the key hypotheses involved to rigorous test. Secondly, most investigators have been content to work with commercial hearing aids. The range of performance characteristics available in commercial hearing aids has been sufficiently restricted so that the question as to what amplification characteristics can be of most benefit to the hard of hearing adult has not really been put to field testing on a research basis. Instead, existing commercial devices have been compared using traditional speech tests which do not even simulate everyday listening situations satisfactorily. Concurrently, only a limited exploration, both in scope and in number of studies, has been made in search for underlying principles and general guidelines. Consequently, the current situation is one wherein hard of hearing adults use as best they can whatever hearing aids happen to be commercially available to them. The professional community offers these persons only superficial help, and it is plagued by unresolved philosophical conflicts which manifest themselves in contradictory techniques for guiding the hearing aid user.

Another problem deserving special comment is that of management for the elderly hard of hearing. We have become acutely aware in recent years that presbycusis (degeneration of hearing in the later years) poses unique problems because of the dysacusis that is so often a predominant feature of the malady. There is no question but that presbycusics need a different form of management than do younger hard of hearing adults. It is trite to add that the problem is both large and growing, since presbycusis is one of the common handicaps in the Nation's expanding population of oldsters; but the proper management of the presbycusic is nonetheless the most frequent adult rehabilitative problem facing us in the hearing field.

Almost the same dearth of research data exists when we consider guidance of the hard of hearing adult. Dr. O'Neill found, as he reviewed the literature, that there have not been any all-inclusive studies in this area during the past ten years, and he discovered that only three currently funded projects might qualify as research on guidance of the hard of hearing adult. He noted particularly that deficits exist in the areas of vocational assistance and improvement in social effectiveness, where ". . . there is need to ascertain which life situations will pose problems to the hard of hearing individual and what specific effects are produced by different types and degrees of hearing loss."

Turning to communicational skills, the situation is similar. We have almost no evidence on the degree of deterioration in speech which the hard of hearing adult may be expected to undergo. Large deficits in our knowledge also appear in the area of auditory training, where there is need to evaluate, over fixed periods of time, the effects that specific auditory inputs have upon the overall receptive communicative behavior. As regards hearing aid use, we have very poor data. It is tragic to note how completely we lack research information here. Dr. Quigley has said, "An extensive search of the literature reveals that very few systematic data have been reported on the educational and rehabilitational management of the elderly adult and most of the reports which do appear are anecdotal." This situation, of course, can not be viewed as unexpected when one remembers that the whole field of research on rehabilitational management of adults with hearing loss has lagged so badly. For example, even the core of background data against which to do differential studies on the needs of presbycusics is lacking. Thus, our deficiencies in the latter area are merely facets of our broader failure to develop penetrating and rigorous investigations on the educational and rehabilitational needs of hard of hearing adults of all ages and types. The unique aspects of management required by the elderly pose only part of a broader gamut of untapped research problems.

5. Interaction of Visual and Auditory Impairments. Rev. Thomas J. Carroll and Dr. Leo H. Riley remarked for the Subcommittee,

> To refer to hearing and sight as the "upper senses" may be outmoded—but we can, perhaps, still safely say that of all the aspects of the human sensorium these two communication modalities have the most immediate impact on human interaction, human maturation, and the development of human personality and behavioral patterns. There is a strong interaction between sight and hearing and particularly between impairments of each.

In consequence, Rev. Carroll and Dr. Riley urged cooperative research and inter-professional collaboration. They pointed to the widely varied topics on which such joint efforts can profitably focus. The other side of the coin is that very little scientific data now exist on these topics. Thus, in considering the interaction of visual and auditory impairments, we find areas of research potential rather than research accomplishments.

For example, the impact of double impairment on preschool children is essentially unexplored except for the small group of severely deaf-blind. It is tragic that children who have partial hearing and partial sight may go undetected even into their school years. Such youngsters must be found and studied in depth much earlier. Only then will we know how double deficits impede personal, social and educational maturation. Only then will we be ready for experimental investigations designed to determine how such children should be managed in their early years.

There is a similar dearth of research data on the merits of procedure to be used in formal education of the partially-sighted and partially-hearing. We have learned empirically that some methods are not fully successful with such children. For example, supplementation of audition with lip reading is often impractical. What we need to find out is how we should handle these children. Here the research task is complicated by the fact that, considering the country at large, children of this type are not often concentrated in groups large enough to facilitate experimentation. Moreover, we do not even know approximately how many such children there are in the country nor what their distribution of relative impairments is. We have a broad investigative assignment ahead of us. We must begin with the tasks of discovering where these children are and what sensory deficits they exhibit. We must then proceed to the tasks of learning how to give them the proper special help during their formal schooling and of mapping realistic vocational education for them.

Adults who, at first have only a handicap of either vision or hearing face their own unique problems of adjustment when they suffer partial disability, in the second sensory modality. Unfortunately, their problems have seldom fired the imagination of investigators, so that we have failed to evolve decisive methods of dealing with these problems. Rev. Carroll and Dr. Riley described the human impact of our current ignorance in this area by commenting as follows about their own work.

> The adjustment center for the blind is presented with numerous problems in the cases of blind persons who show a hearing loss which might be considered within their age grouping, yet which may seriously interfere with one or another aspect of their training. To our knowledge, at this time in history no one in the field of audiology can tell us with certainty when a hearing aid should or should not be prescribed for such persons, what its spectrum should be, and, in general, what type should be used. For example, consider the . . . middle-aged person with somewhat impaired hearing who, with sight has had little difficulty in taking part in conversations . . . because . . . he was making use of speech reading and the interpretion of facial expression. With loss of sight, he suddenly finds himself unable to "hear" as well as he could previously. But the prescription of a hearing aid designed for the speech spectrum

> might well interfere with the reception of other sounds which he now needs as cues for purposes of spatial orientation and mobility. Or, again, consider the problem of the blind person whose hearing loss is not so much in the speech range as in the range of sounds needed to make use of in obstacle detection. What hearing aid is available to restore this portion of the spectrum, and what about the placement of the receiver and/or receivers and their nature?

The last example in the foregoing paragraph gets into the topic of echolocation, which is so essential to the blind. Some research has been going on over the years on this subject, but fuller interdisciplinary cooperation is possible. The whole question of mobility skills of the blind is involved. Rev. Carroll and Dr. Riley told us:

> Every professional in the rehabilitation of blind persons is aware of the fact that there is some correlation between ability in hearing and ability in making use of mobility skills—but no audiologist has given the exact correlation.

And, speaking of the new mobility aids that are being developed, they added:

> It is important to researchers to know to what extent the hearing channel should be used for introducing the signal of the device and to what degree it interferes with the auditory cues received from the general environment which are of such importance to many blind persons.

Other deficits in our knowledge, ranging from the use of reading machines to the attitudinal problems that attend double handicap, could be mentioned. They all bespeak need for research. Suffice it here, however, to emphasize only one more area: namely, that of our elderly persons with serious visual as well as serious auditory handicaps. We do not even have good figures on the incidence of such individuals. Moreover, as Rev. Carroll and Dr. Riley stress:

> Dealing with the multiple traumatic effect of these losses calls for more knowledge than seems to be available today. Here certainly is an area for massive cooperative effort between those in the visual and those in the aural fields.

In conclusion, the human values at stake when visual and aural impairments coexist are quickly perceived, but investigative attack which will show us how to cope effectively with the problems of the doubly handicapped has hardly begun.

B. *Research Needs*. The overall generalization to be derived from the foregoing discussion is that almost all the basic research on the educational and rehabilitational management of acoustical disorders awaits doing. The performance of this research represents an arduous and complicated undertaking.

Such being the case it is unrealistic in this report to attempt an exhaustive detailing of specific research problems. The more reasonable approach is to define relatively briefly some of the major needs involved and to illustrate a few of the problems these encompass. It is with this purpose in mind, and with full recognition that no expert reading the following paragraphs will feel that they do justice to his particular sphere of interest, that the Subcommittee presents the following summary.

1. Need for Surveys. It is clear that we do not know either the exact natures nor the scopes of most of our problems. We must have more carefully designed epidemological studies to define the prevalences, incidences, etiologies and characteristics of hearing impairments that occur alone, as well as those that occur in combination with other disorders. Only with such information in hand can we develop adequate programs for pre-schoolers, for school age children, for younger adults and for the elderly. We must also have surveys of other types, covering topics like the employment status of the deaf, of the hard of hearing and of the doubly handicapped.

2. Need for Determining Impact of Early Auditory Impairment. The question as to how deprivation of auditory experience in early life modifies and interferes with the acquisition of communicative skills is of prime research importance. It is, moreover, a question with many ramifications. These range from the sub-question of the special deprivations which face the deaf infant to the sub-question as to what subtle residues of auditory deprivation plague an adult who has been hard of hearing throughout life.

3. Need for Refinement of Tests for Children. A fully successful attack on a child's educational problem must start with correct definition of that problem. Despite the heavy attention which has been and is being given to perfection of auditory tests, we lack the tools for quantifying auditory deficits as we should. This is true whether we are considering the measurement of acuity levels in very young children or testing achievements and capacities for speech hearing in older youngsters. Moreover, research endeavors in this area must cope with the problem of developing tests for language achievement and of linguistic potential.

4. Need for Clarification on Parental Guidance. We simply do not have a clear-cut, cohesive body of knowledge as to how children with hearing problems should be handled, and hence no firm basis for guiding parents in their management of their own children either as pre-schoolers or later. As Silverman pointed out to our Subcommittee, professionals disagree among themselves so radically that parents often have great difficulty knowing what

long-term goals to hold for their children. Research is needed to answer such questions as, "Should early stimulation with amplification be unisensory?" or "Should the deaf be trained primarily for a life in their own sub-culture, or what?" Only with such answers at hand can unified aims assuring proper parental guidance be achieved and appropriate long-term programs established for parents to follow.

5. Need for Linguistic Research. The knowledge acquired by modern linguistics, and also its research techniques, must be applied to the problems of acoustically handicapped children. One search must be for better understanding of language processes. Another must be for methods of incorporating developmental linguistics into more efficient systems of teaching language comprehension and expression to children with hearing problems. Still another must be analysis, through the techniques of linguistics, of the language manipulation patterns of the deaf and hard of hearing. From such searches it is only a short step to development of programmed language training materials or to the application of modern linguistic approaches to auditory training or lip-reading instruction.

6. Need for Resolution of Educational Goals for the Deaf. There are broad problems in education of the deaf which need clarification. Means of truly keeping track of the individual student's unique requirements must be perfected. Moreover, the traditional conflicts within the field of education of the deaf must be resolved objectively. These conflicts cover issues like 1) oral vs. manual instruction and 2) segregated vs. integrated school placement.

7. Need to Narrow Educational Gap for the Deaf. Deaf children become educationally retarded irrespective of the training system they undergo, and hence particular research effort is called for in seeking methods and procedures for bringing their academic deficits to the irreducible minimum.

8. Need for Special Study of Deaf Children. Many special questions bearing on deaf children should be investigated systematically. For example, we must clarify the subtleties of "conceptualization" in the deaf, i.e., what role in this process does gesturing play? We must ascertain the best use of audio-visual aids for the deaf. Or, again, we must clarify the guidelines for their vocational training. And so on.

9. Need to Determine Proper Role of Special Devices. Modern technology has achieved systems for transposing ordinary speech signals into stimulus realms within which the deaf are responsive. "Visible speech" brings the eye such transpositions, and there have recently been developed systems for moving sound into the low frequency range where many deaf have some auditory responses. We must discover not only to what extent such transposition systems supply truly useful information but also to what extent they complicate the reception of communcation from others. It is particularly important to discover both the conditions in which special devices are effective and those in which they are not. A related problem is the desirability of finding a truly useful orthographic system for representing speech graphically.

10. Need for Improved Methods of Teaching Communication Skills to the Deaf. The techniques now in use for developing the ability of the deaf to understand others and to express themselves to others have reached high levels of competence, but these techniques have evolved primarily from the empirical experience of teachers. We must conduct systematic study of the relative efficiencies of old and new teaching methods. A broad analysis of the speaking process, using the sophisticated laboratory procedures of speech science, should yield increased understanding of the task to be accomplished with the deaf and should indicate methods for proceeding. The same is true of the lipreading act. Here, moreover, concentrated efforts are required to learn how to incorporate training that covers the "contingency tables" of language and the redundancies of its expression (both verbal and physiological). There is also the prospect of discovering innovations in communicative training we do not now envision. Finally, there is need to devise some system whereby each child in a deaf class can get much more *individual* drill in communication skills (particularly speech production) than is possible under present arrangements.

11. Need for Adult Education for the Deaf. Persons with extreme auditory deficits can benefit from continuing special training after they reach adulthood. However, extensive research is essential if we are to learn 1) how best to maintain and improve their communicative skills and language abilities and 2) how best to continue academic advancement beyond the fifth grade level which now is so frequently the ceiling of their achievement.

12. Need for Improvement in Vocational Training. Although great strides have been made in modernizing vocational training for the deaf and even though the National Technical Institute for the Deaf has fortunately come into being, substantial attention must be given to preparing the deaf for gainful and emotionally satisfying employment. Particular concern needs to be shown for improving the management of the adult deaf of only mediocre talents and the individual whose deafness is delayed until he is in his gainful years. Research in these areas must coordinate information on occupational levels with information on the limitations to job performance that arise when deafness occurs. Such

research will remain an ongoing area of need as long as the occupational opportunities in our society keep changing.

13. Need for Improved Guidance of the Adult Deaf. Guidance of adult deaf persons includes more than concern for their requirements for training in the academic communicative and vocational realms. It covers also the social, emotional and personal facets of their lives. Extensive investigations in these latter realms are sorely needed, too. Questions such as how the deaf person best fits the hearing world or how to give him an appropriate wealth and depth of social experience should have very high priority. So should investigation of personality characteristics and emotional maturation. For example, there is great need for techniques that will help identify accurately and evaluate correctly the psychological disorders that appear in the adult deaf population.

14. Need for Resolution of Goals for Hard of Hearing Children. The educational guidelines for such children should be clarified through systematic research. The primary questions are, "What types of training should be given to which categories of child in what kinds of environments?" and "By whom should this training be given?" For example, "What are the circumstances, if any, when it is preferable to bring hard of hearing children with relatively severe hearing impairments together in segregated day-long classes?" or, again, "Can the needs of the mildly impaired child be handled satisfactorily by an itinerant speech clinician or is some other kind of instruction to be preferred?" One aspect of this need for clarification is the task of defining the advisory role of audiological clinics and other diagnostic centers in the management of hard of hearing children. Advice from such centers should be consistent with what is in truth educationally preferable for each child. A good starting point in attacking this last problem would be to analyze the files of those few centers with good data on children who have been followed for several years.

15. Need for Special Study of Hard of Hearing Children. A variety of special questions regarding the hard of hearing child should be investigated. One covers the relationship between patterns of hearing loss and defects in speech production. Another covers growth and maturation of the child's ability to use his residual hearing after the introduction of appropriate amplification. A third involves the diverse issues centering around vocational education of such children. And so on.

16. Need to Determine Proper Role of Hearing Aids. The fact that hard of hearing children have substantial residual capacity means that amplified sound must be integrated into the child's life to the full extent that his residual capacity warrants. The question before us is, "How and when is amplification to be incorporated?" Contemporary wearable hearing aids are poor sound reproducers which for some children may garble incoming information to the point where it has poor usefulness, but classroom amplifiers with their better acoustic characteristics are not portable. Which children can profitably start with the wearable device and which must be initiated to amplification via better fidelity equipment? How should the transition from classroom to extramural situations be made? Under what everyday circumstances, if any, should a child not wear a hearing aid? When should binaural instruments be employed, and what special requirements are imposed when they are? And so on.

17. Need for Improved Hearing Aids. Contemporary wearable hearing aids are, almost exclusively, built to satisfy the adult market. Children, by virtue of the fact that they must acquire communicational and linguistic skills largely through hearing, have more rigorous acoustic needs than do adults who must merely keep habituated auditory skills active. Also, children are rougher with hearing aids than adults. A major need is development of "child-proof" hearing aids with substantially improved electroacoustic response.

18. Need for Improved Procedures for Refining Communication Skills of Hard of Hearing Children. Miriam Hardy exemplified this need well when she stated for the Subcommittee that we should develop 1) ". . . new measures for assessing auditory function in terms of how auditory information is transmitted, recognized, retained and integrated, in quiet, in noise, and with competing messages and at various distances . . ." and then should apply 2) ". . . this information to the development of more effective procedures for auditory training which is tightly bound to linguistic structures, forms and meaning;" and also, we should make 3) ". . . a concentrated effort to determine what factors are critical for lipreading skill, and new linguistic approaches to the teaching of lipreading."

19. Need for Resolution of Goals for Hard of Hearing Adults. We do not have good sociological understanding of hard of hearing adults. We can not even catalogue the sociological sub-types within the hard of hearing population. Intensive research must be performed before we will truly know the rehabilitational requirements of these sub-types. We need data on such questions as the scope of effectiveness of their social activities, the difference in communicational and other efficiencies with variations in severity of impairment, configuration of impairment and duration of impairment. We have notable need to validate our audiological tests against work-a-day communicational efficiencies exhibited by hard of hearing adults so that we can better judge the practical impact of a person's hear-

ing impairment. In addition, we must do appropriate follow-up studies on the rehabilitative procedures we are employing so as to gain a clearer picture of the strengths and weaknesses of these procedures. This area also includes development of better rehabilitative sequences.

20. Need for Special Study of Hard of Hearing Adults. A variety of special questions regarding the hard of hearing adult should be investigated. For example, we should delve into the problems of adjustment which arise with the onset of a communicatively handicapping hearing impairment after a person has reached adulthood. These problems are attitudinal, social and economic. Or, again, we could use to advantage good tests for ascertaining the patient's potential for benefit from therapy, whether general or in the communicational realm, and for measuring therapeutic successes. A problem of major importance, to take another illustration, is why most hard of hearing adults approach rehabilitation programs lackadaisically.

21. Need for Research on Hearing Aids and Their Use. Our knowledge regarding the efficiencies which adults achieve in everyday life with hearing aids is woefully sparse. Considering the central role in rehabilitation which the hearing aid can play for its user, we have need for a major attack upon all the problems encompassed by this topic. We must determine such things as 1) which dimensions of hearing aid performance are critical for which types of hearing loss, 2) what breakdowns in listening success occur with hearing aids when competing sounds are present, 3) under what circumstances two hearings aids are desirable, 4) how best to select an instrument for a user (including development of new and realistic tests), 5) what persons require special circuitry, 6) what programs in orientation and training in hearing aid use are effective and practical. A related need, of course, is for technological improvement of hearing aid components and circuit combinations.

22. Need for Improved Rehabilitation of Communicational Skills. Auditory training, lipreading and training for retention of speech skills (for the severely impaired) have constituted the rehabilitative attack on communicational skills. The significances and proper emphases of all these approaches must be re-evaluated through systematic research, including use of demonstration projects. To what degree, for example, have modern otologic surgery and the contemporary hearing aid lessened need for hard of hearing adults to acquire highly refined lipreading skill? How persistent are good speech habits, even without special training, in the face of substantial hearing loss? What extent and kinds of auditory training really benefit the new hearing aid user—and to what degree should this training be unisensory in contrast to a combination of auditory training and lipreading? How should the training program be adapted to incorporate the full range of communicational situations encountered in everyday life? How should general psychosocial guidance be coordinated with communicational rehabilitation? How does good communicational rehabilitation affect psychosocial behavior? And so on.

23. Need to Assess Listening Situations. Reference has been made periodically within the preceding paragraphs to the need to determine listening efficiency in work-a-day situations. Each reference dealt with the problem of the group then under consideration. We also have a general need to define the characteristics of different listening situations, embodying major types of sound competition and of communicational demand, and then of assessing the way in which variations in hearing (aided as well as unaided) modify performance in such situations. In other words, we must research the question of the utilization of residual hearing in the environments where residual hearing will actually be used.

24. Need for Special Study of Presbycusics. The hearing difficulties that come with old age pose problems both for their possessors and for the professionals who seek to help counteract them. Special studies of many varieties are needed here. We must ascertain how to guide the presbycusic and his family to adjust to his problems. The role of hearing aids for such people must be clarified. Why do some presbycusics get such poor help from hearing aids? How can the elderly best be oriented to hearing aid use? Other phases of rehabilitation, such as lipreading, need assessment. Can lipreading skill actually be improved appreciably in the elderly? Which elderly people benefit from this form of rehabilitation? Why are some so poorly motivated? And, as a final illustration, the inter-relationships between hearing impairment and the other processes of aging require exploration.

25. Need for Special Study of Double Handicapped (Visual and Auditory). The scope of problems calling for research attention here ranges from that of the impact of double handicap on the communico-linguistic development of the very young child to its impact on the elderly person with newly acquired restriction in both modalities. We must discover the special techniques which are required in parental guidance, in general educational management, in special training in linguistic and communicational skills, in vocational education, in personal and socio-economic adjustment and in rehabilitation. The uniqueness of the management needs of the doubly handicapped is illustrated by the paradox which wearable hearing aids pose. Contemporary instruments are sufficiently restricted in frequency range so that restoration of a doubly im-

paired person's ability to again hear conversational speech may well be accompanied by the penalty of poor reproduction of other sounds essential to the blind person's mobility and to his full perceptual evaluation of the happenings in his environment. Methods of solving this paradox, and the other special problems of the doubly handicapped must be found.

26. Need for Clarification of Audiological Requirements of the Blind. Blind persons make special use of the normal hearing sense. The nature of this use poses important research areas for experts in audition. One question centers on how much the auditory system may be usurped by sounds generated artificially by devices designed to assist the blind in obstacle sensing before these new sounds disrupt the communicational and other ordinary uses of hearing. Another area of great importance is that of discovering how blind persons can best learn to use ordinary environmental sounds in their obstacle sensing tasks. For example, are different auditory mechanisms brought into play as the distance to the obstacle changes? A third illustration involves discovery of the degree to which speech can be compressed to speed up talking books. Here one finds such complications as the fact that elderly people often find rapid speech unintelligible.

27. Summary. The foregoing paragraphs have listed twenty-six general areas of research need centering in one way or another on the management of persons with impaired hearing. This listing runs the gamut from the need for early identification of the auditorially defective infant to the need for defining the special requirements of the deaf-blind. It covers topics as diverse as the education of the deaf child and the rehabilitation of elderly persons with mild losses. This listing gives a reasonably comprehensive picture of the facets in management of the hearing impaired which need attack through research, but this listing must be recognized as illustrating the scope of the investigative challenge before us, rather than as a comprehensive catalogue of research needs.

C. *Training Needs.* There are acute shortages in research workers, teachers and clinicians equipped to deal with the areas reviewed in the foregoing section. The exact dimensions of these deficits can not currently be stated with any surety. Only as scientific study defines these areas adequately can personnel needs be projected with accuracy. Consequently, the discussion which follows does not attempt to specify the magnitudes of the training programs that must be instituted to overcome current shortages. Suffice it to point out that any reasonable level of new support for such programs and any reasonable expectation in recruiting competent trainees will fall short of satisfying the demand, at least during the next decade. The first requirement is to expand as much as practical our support of training in this field. Doing so will lessen the personnel deficit but will not eliminate it. We can be sure that it will be a long time before training programs in these areas will have reached the size where they should be leveled off.

With this general comment as background, we turn now to more specific comments on the shortage of research workers and of teachers and clinicians.

1. Need for Research Personnel. Dr. Lowell epitomized the situation as it applies to all the areas under consideration when he wrote for the Subcommittee the following comment directed toward education of the deaf:

> The lack of measuring instruments has seriously impeded the development of a sound research program on the education of the deaf. Behavioral scientists interested in special education have generally not been of top caliber. For example, no researchers in special education have been invited to the Institute of Advanced Study in the Behavioral Sciences at Stanford. An entirely new program is needed if we are to develop the climate that will attract competent research personnel.

The crucial thrust of Dr. Lowell's comment is that we must develop concurrently both a new breed of researchers and a new research climate. It is this last point that stands paramount. We can not simply presume that expansion of existing programs will supply the research personnel required to perform the varied studies encompassed by the research needs outlined above.

To be sure, many of the studies alluded to in the preceding discussion do fall within the purview of recognized divisions in the behavioral sciences. Such studies can very profitably be undertaken by persons trained in existing programs. In this regard it is particularly important to stress that individuals receiving pre- and post-doctoral training under NINDS-supported programs in the communicative sciences can cope with many of the research problems at issue, such as those involving speech of the acoustically handicapped, the use of hearing aids, the analysis of speech, or the communicational evaluation of listening environments. Thus, one important way of increasing research personnel for work in the areas under discussion is to expand existing NINDS training programs in the communicative sciences and to launch others of the same types.

In addition, however, a major effort is needed to develop training programs with new orientations. It may be that such programs belong in academic environments unlike our contemporary environments that are focussed on special education, education of the deaf or clinical audiology. These new programs must be multidisciplinary, bringing together skills as diverse as those of the acoustician, the linguist, the otologist, the audiologist, the experimental psychologist, social psychologist, the sociologist, the clinical psychologist, the psychiatrist, the bio-engineer, the educator, the geriatrician and others. Obviously, no single multidisciplinary program of this type can expect to emphasize in depth all of the areas we have just outlined. The crucial requirement for each such program must be that it is primarily committed to the preparation of researchers committed to concentrate either 1) on scientific definition of the problems of the acoustically impaired, 2) on amassing the basic knowledge requisite to understand the problems of the acoustically impaired or 3) on scientific investigation of methods for coping with these problems. This goal can be achieved only if such multidisciplinary programs conceive of themselves as being the birthplaces for a new sub-specialty within the behavioral sciences. We may then look to the graduates of these multidisciplinary programs for a vigorous and innovation-rich attack, through research, on the education and management of the acoustically impaired. A good illustration of the kind of new empasis that can be achieved is found in the plea which Rev. Carroll and Dr. Riley made to our Subcommittee. These men asked for pre-doctoral fellowships to prepare scientists knowledgeable in fields of both visual and aural impairment. These writers mentioned an array of problems that such scientists would be uniquely equipped to investigate once appropriate training programs produce them for us.

2. Need for Teaching Personnel. There is a clearly recognized need for more and better prepared teachers to work both with deaf children and with the hard of hearing child. In consequence, the annual expenditure for preparation of special teachers to deal with acoustically handicapped children has been better than $2,500,000 in the immediate past. The Subcommittee is pleased to note this fact. The Subcommittee must emphasize, however, that there is lack of comparable emphasis upon preparation of teachers to deal with the adult acoustically impaired. Such teachers are needed to offer vocational training, in continuation instruction in communicative and linguistic skills, and in adult education covering academic and cultural subjects.

3. Need for Clinical Personnel. The authorities consulted by the Subcommittee pointed out that there are needs for many kinds of clinical personnel. The tasks of these individuals are to perform the many identificational, habitational and rehabilitational tasks which are required by the acoustically handicapped.

The Subcommittee is not attempting here to define these areas of training need, since they involve preparation of persons whose efforts will not be primarily in the research field and, hence, represent areas of training outside the scope of inquiry assigned to the Subcommittee. However, the scope of personnel encompassed is illustrated by the fact that the consultants listed needs as diverse as the following: personnel skilled in guiding parents of the acoustically impaired; diagnosticians with multidisciplinary training in identifying and defining early hearing, visual or perceptual or other difficulties; rehabilitational audiologists; vocational counsellors and other guidance experts skilled in the special needs of the acoustically handicapped; clinical psychologists and psychiatrists uniquely knowledgeable in this area; people specially prepared to work with presbycusics; experts in the problems of the adult doubly handicapped (including psychiatrists attuned to the problems of such persons); and the like.

V. Concluding Comment

The foregoing chapter has reviewed the present status of knowledge about the auditory system and its functions, about pathology of the auditory system in relation to hearing and about educational and rehabilitative management of auditory disorders.

On the basis of this resume, the Subcommittee identified fifty-eight separate aspects of audition and its disorders which are badly in need of attack through research. The Subcommittee made no pretense, in preparing this compilation, of exhausting the list of research needs. Instead the tabulation is presented as a diverse and illustrative sampling of the research areas in audition that should properly receive substantial support from NINDS in view of the mission which is the Institute's assignment from Congress. Some of these areas encompass the basic sciences underlying normal auditory phenomena. These sciences supply the cyclorama against which to understand pathologies of audition and their management. The remainder of the research areas deal directly with disorders of the hearing mechanism, the hearing process or the communicative handicaps imposed by disordered hearing. The generalization which emerges is that much financial support, many professional specialties and monumental investigative endeavor must be blended if the research needs illustrated in this chapter are to be adequately attacked.

Within this frame of reference, a most appalling bottleneck exists. Judged on the basis of the task at hand, there are far too few investigators concentrating on the scientific study of hearing and its disorders. Moreover, the number of future scientists now preparing for such work is very small. Finally, whole aspects of the research thrust must remain in abeyance until new interdisciplinary linkages evolve.

Chapter 4—RESEARCH ON CENTRAL PROCESSES

I. INTRODUCTION

It is a truism that man's ability to communicate with verbal symbols is probably his most distinctive characteristic. In terms of human development, the sensory system that makes hearing possible is fundamental to the functions of symbol-integration, memory and recall, all of which are involved in the emergence of language and speech. Man's unique achievement is the capacity to attach meaning to symbols. It has been said that the development and use of language involves word-sound-units, word-concept-units and word-formation-units, all being interlocked aspects of temporal integration (what the brain does in managing rapidly following bits of information as the listener attends to the talker, and assigns meanings to what he hears) under the control of the entire centrencephalic system (Penfield and Roberts, *Speech and Brain Mechanisms*, Princeton, New Jersey: Princeton University Press, 1959). In brief, in many respects we talk because-and-as we hear.

It has been made clear in this report that hearing is the sensory function which permits an organism to respond to various classes of acoustic stimuli. We live in a world of sounds, and commonly must select among them what we attend to. On the other hand, the function we call language involves a system of communication among persons who have grouped themselves together and therefore developed a community wherein certain symbols—both verbal and visual—possess arbitrary conventional meanings. (There are other kinds of language: for instance, gesturing or signing may constitute a language, but it is of a lower order in both comprehension and expression than verbal-symbolic language.)

It would be presumptuous in this brief compass to undertake to express or to summarize the inquiries of the past many years into the several topics related to the comprehension and use of language. Certain kinds of information are reasonably available and clear. Much more, however, is not. It remains a fact that we do not yet know precisely how we hear (or learn to hear), nor how we learn to manage the intricate components of language and speech that make communication possible. All this is only the more complex when we undertake to relate what is known about anatomy and physiology with the kinds of behavior that result from interferences or interruptions or maldevelopment of the "central processes" of communication, many of which are subsumed under the general title of "communicative disorder

Of special importance in all these references is that man has two brains, connected in various ways, but each nonetheless capable of serving different functions, all of which contribute to man as a communicating person. Much that is in reference relates to hearing, language, and speech—the usual communicative trilogy—but equally pertinent, at least in literate man who learns to expand his intellectual horizons, is reading. There are many kinds of problems that have been associated with reading disabilities, one of which is dyslexia which reflects a primary breakdown in the relations of cortical processes of differentiation and integration, and is perhaps quite comparable with dysacusis. It may be that together these two forms of involvement of the central nervous system may make quite explicit the functions of the two brains. In most persons who are right handed the left hemisphere is the center of the generation of speech and leads the way in the relationships of temporal processing and pattern making that are implicit in learning, comprehending, and using language. In the same persons, the right hemisphere—at least by inference from current findings—has more to do with spatial relations, and with refined aspects of time and space in man's use of verbal symbols (Pribram, in *Interhemispheric Relations and Cerebral Dominance*, Vernon, B., ed., Baltimore, Johns Hopkins Press, 1962, 107-111; Masland, Section III, A of this chapter). There is much support for this concept. Effects of cortical stimulation during craniotomy indicate that visuo-spatial tasks are more affected by lesions in the right hemisphere, and verbal learning and memory more affected by lesions in the left hemisphere (Milner, B., Psychological Defects Produced by Temporal Lobe Excision, *Research Publications of the Association for Research in Nervous and Mental Diseases*, 36, 1958, 244-257). In another series of experiments the same investigator presented conflicting bilateral stimulation (using a series of three digits) which caused verbal material to be "favored" as it reached the ear opposite from the dominant temporal lobe.

There are some anomalies in the basic hypothesis, however, for there have been young children subject to seizures who have had the cortex of the left hemisphere removed and have continued to talk. In the young, then, the right hemisphere can do this if the task is forced upon it (Masland, *op. cit.*). How can there be young children with language disabilities, as there most certainly are? One possibility is the presence of bilateral lesions; another is that there is interference below the cortex in the brain stem. A third is that there is a constitutional incapacity, for whatever reason, which interferes with normal functions of integration and association and thus with normal functions of integration and association and thus with language learning. This is what has been referred to as developmental aplasia [Wepman, J. M., Cerebral Injury or Agenesis—A Concept of Delayed Development, in *Conference on Children with Minimal Brain Impairment* (S. A. Kirk and W. Becker, eds.), Easter Seal Research Foundation, 1963; Hardy, W. G., On Language Disorders in Young Children: A Reorganization of Thinking, *Journal of Speech and Hearing Disorders*, 30 (1965), 3-16].

Perhaps it should be re-emphasized that most of the detailed thinking about language functions and language disorders is conjectural, and hypothetical. Our limited information has been obtained from a relatively few experimental observations. There are some indications that disturbances in adult aphasics (about which more is known than is known about language disturbed children) do, indeed, reflect some aspects of the problems of a child who cannot naturally learn language and speech. It may well be that the problems in the young are in many ways modified in comparison with the effects of post-stroke adult aphasia.

Perhaps equally important—but as yet relatively little studied—is reference to feedback mechanisms operating within the sensory system. It is now apparent that every sensory system in the body has a feedback mechanism through which input is regulated at various levels. The auditory system is no exception. Efferent pathways to the ear have been demonstrated and it is reasonably certain that there are feedback stations directly related to the function of the cochlear nuclei and the brain stem. It is quite possible that they play a role in children with delayed development of language, with some aspects of adult aphasia, and with some of the atrophic difficulties of the elderly. Again, although it is easier to study hearing, language and speech as though each were a kind of entity, the fact remains that in both normal and deviant function none can be separated from the others.

It is obvious that there are many ramifications of study of the central communicative processes, and that no single person can nor should assume responsibility for them. So much remains unknown that even the organization of pertinent materials offers an almost impossible task. By general agreement these days, any address to the central processes pertinent in communication requires interdisciplinary inquiry and management. Accordingly, the Subcommittee enlisted,as it prepared this chapter, the help of various experts in neurology, neurosurgery, psychophysiology, the behavioral sciences in general, and several specialists in language disorders. Responses were most useful. Some of the material has been rephrased in presentation in this chapter. Where this has been done, acknowledgement has been made of the resource person. Some of this material is so compact, however, and the range of the subject matter so diverse, that it seemed a sensible course to reproduce it here in the consultant's own words.

II. SOME CHARACTERISTICS OF THE CENTRAL SEGMENT IN THE COMMUNICATIVE PROCESS

One of our consultants, Dr. William D. Neff, offers some ideas about the structural details of the "central segment." He contributes information based upon his own work in sensory discrimination, and in some aspects of transmission and integration that contribute to it. He has taken the trouble, as well, to put his mind to an outline of some of the many unanswered problems that relate to all these matters under consideration. His statement comprises the remainder of this section.

A. *Structural details.* The principal afferent pathways of the sensory systems are fairly well known in many animals, including man. The connections from the primary systems to associated systems, such as the diffuse thalamo-cortical projection system (in mammals) and the brain-stem reticular formation have not been defined clearly by anatomical techniques. In the case of the auditory system there is also evidence from behavioral and neurophysiological experiments that suggests that, outside of the primary afferent pathways, there are other rapid conducting pathways (few synapses) between cochlea and cortex. These have not been discovered by standard anatomical methods.

Recurrent efferent pathways have been described in most of the sensory systems. Many details of these pathways remain to be clarified.

Information is incomplete about connections between the sensory systems, associated systems and motor systems.

Anatomical information is lacking as the sensori-motor connections that provide for reflex responses (both of skeletal and autonomic muscles) to sensory stimuli.

Developmental and comparative studies of structures in the central segment of sensory systems have been few in recent years. There are only a very small number of neuroanatomists with experience and training in these fields. Consequently, few new students are educated to carry on developmental and comparative investigation.

B. *Physiological processes; transmission and integration; learned sensory discrimination.* The projection of sensory end-organs on centers of the CNS has been studied in many species of animals, first by using gross electrodes that looked at activity of many cells and, in recent years, by using microelectrodes to look at activity of single units. Much has been learned about the anatomical organization of the systems through these techniques, for example, the multiple projection of sense organs on higher centers and the topographic projection to such receptors as cochlea, retina, and tactual end-organs of the skin. The functional significance of multiple projection is not clear; the same is true of topographic organization.

Electrophysiological experiments have also provided some data on how information is coded in different sensory systems. Knowledge of coding mechanisms has been limited by the lack of experiments on unanesthetized preparations and the difficulties encountered in studying the interaction of two or more individual units at one time. Improvement in techniques of recording and the use of computers to process and analyze data recorded should lead to important advances in understanding transmission and coding of sensory information.

It is obviously impossible to simultaneously record from a large number of adjacent cells using individual microelectrodes. Samples of activity can be obtained and interaction among a few units observed. The electronic computer is important for work at this level. An even more important use of the computer will be to simulate parts and perhaps eventually all of a sensory system. Simulation plus comparison between the simulated system and the real sensory system looks like a promising approach. As of today, this approach has been talked about, but very little has been done that is acceptable to the neurophysiologist as well as the computer expert.

Other techniques that show promise but that have been used in only a very limited number of experiments on sensory systems are: (a) the injection of information into a sensory system by implanting electrodes in centers or paths of the system and producing excitation by electric shock; and (b) recording electrical activity during behavior initiated and guided by sensory signals. In both cases gross or microelectrodes are implanted so that records can be obtained from the unanesthetized preparation. These techniques will help to discover the ways in which information is coded in sensory systems and may also suggest some of the changes that take place during the learning of a sensory discrimination. From a practical clinical standpoint, direct electrical stimulation of neural centers or pathways should appear to be the only way of making the system functional when the peripheral end-organ is destroyed. It should be emphasized that, at present, we do not know what patterns (spatial and temporal) of impulses to inject into a sensory system in order to produce different sensory experiences.

From behavioral studies of sensory discrimination before and after ablation of central structures we have a reasonable amount of knowledge about the parts of the central nervous system that are necessary for different kinds of discrimination.

We can only begin to build models that suggest how the real sensory systems may work. The use of the ablation method in experimental animals and the study of human patients with CNS damage have not been fully exploited. As new information about structure becomes available and as new techniques of experimental surgery are developed, laboratory experiments and clinical investigations should lead to a better understanding of sensory systems in terms of the parts played by different centers and major pathways. This kind of knowledge of sensory systems is needed even when we obtain more and more detailed information about the activity of smaller elements in the system.

In order to produce a model of any sensory system, all lines of evidence (structural, electrophysiological, behavioral) will eventually be needed.

The role of neurochemical changes in learning and remembering sensory discriminations is completely unknown. Many advances in this field are to be expected as an increasing number of biochemists become interested in the study of the central nervous system.

C. *Some unanswered problems.*

1. Mechanism of excitation of first-order neuron by sensory receptor.

2. Peripheral coding of primary sensory qualities—for example:

   a. For hearing—pitch, loudness, duration, localization of sound in space.

   b. For vision—brightness, hue, localization in space.

3. Recording in neural centers. For example:

Is pitch a matter of place (which neurons excited) or frequency following or both? Is information about location of sound in space coded in terms of temporal events in the nervous system or transformed at some level so that it is transmitted to higher centers in terms of spatial events?

4. Are there separate pathways for carrying information about different sensory qualities or are all or many of the same neural units involved for each kind of information? For example:

Is the multiple projection of cochlea on the primary cochlear nucleus and that of the latter on higher centers, a means for providing separate channels for different classes of information?

Are the bipolar cells in the medial accessory superior olivary nucleus especially designed to receive and transmit binaural information?

5. Are there centers that are merely relay centers or does some processing of information (dividing, amplifying, recoding) take place in each center?

6. By what mechanism does short-term storage of sensory information take place? For example:

In discrimination of the difference between two temporal patterns of sound, each of which contains similar components (low-high-low vs. high-low-high) short-term storage is necessary in order that second pattern can be compared with first. Is this storage a matter of continuing nerve impulses, a chemical change, or what?

7. By what mechanism does long-term storage (memory) occur?

What change has taken place in the brain when an animal has learned to make a given response to an auditory signal or a child has learned to understand a new word?

III. Nature and Scope of Central Processes

Within fairly recent years many diverse views have been expressed about definitions of language and language disorders; what is aphasia? There have been several international conferences on various aspects of many questions concerning "the central factors" of communication, and it is clear from study of the conference proceedings that there is considerable disarray regarding the nature and scope of aphasia. Without doubt, a basic problem comes from lack of measurements, of ability to determine degrees in extent of or effect of impairment. There is a recurrent thread of an age-old dependence on clinical impression. In general most current thinkers in the field are quite discontented with a classical descriptive dichotomy: receptive and expressive aphasia.

The purpose of the following inclusions in the report is to offer three somewhat different points of view regarding some of these matters of definition and current needs in research and study.

A. *Brain Mechanisms Underlying the Language Function.* The first is a paper by Dr. Richard L. Masland. We are grateful to Dr. Masland and to The Orton Society, who published this paper in 1967, for permission to reproduce it in its entirety. This paper is based on an address given at the Seventeenth Annual Meeting of the Orton Society, October 28, 1966, Rockefeller University, New York City.

BRAIN MECHANISMS UNDERLYING THE LANGUAGE FUNCTION

by Richard L. Masland, M.D.

It is appropriate and in keeping with the long history of The Orton Society and the tradition of Dr. Orton's work to discuss the relationship between the problems of language and the underlying structures and brain mechanisms upon which language depends. As you know, there are two ways of studying a mechanism. One is to put something into the input and study what comes out of the output without worrying too much about what is inside the box. This is spoken of as the "black box" technique. The other is to remove the cover and see what you can learn about the works which are inside.

There are advantages in attempting to relate performance with underlying structure and this is the purpose of this presentation. I propose to review various studies on the question, "how do language functions relate to the structures and activities of the brain?"

In regard to the underlying structures required for language we have some rather definitive information. First, in regard to the relationship of hemisphere and handedness to the language function:

Table 4-1 (Penfield and Roberts, 1959) summarizes a study of a group of individuals who experienced language impairment subsequent to brain operation. Of a total of 157 persons who were right-handed and who had an operation on the left side of the brain, 78 per cent developed aphasia. Similarly, of those who were left-handed and who had an operation on left side of the brain 72 percent became aphasic. Therefore, even in left-handed individuals

	Left Hemisphere			Right Hemisphere			
Hand	Total No.	No. with Aphasia	%	Total No.	No. with Aphasia	%	Significance of Difference
R[1]	157	115	78.2	196	1	0.5	<.001
L[2]	18	13	72.2	15	1	6.7	<.001
Total	175	128	73.1	211	2	0.9	<.001

[1] Including predominantly right

[2] Including predominantly left

Table 4-1. Difference in percentage of patients without injury before two years of age and with aphasia after operation on the left and right hemisphere. (Penfield and Roberts, 1959)

in this study a large majority still had the center for language located on the left side of the brain. Of those who were operated on the right hemisphere, you find that of those who were right-handed, only 0.5 per cent developed aphasia, whereas of those who were left-handed (15 individuals having an operation on the right hemisphere) 6 per cent developed aphasia—a slightly greater figure. But the significance of this is that the dominant hemisphere for language is most often the left one and that even in individuals who are left-handed by ordinary standards, the left hemisphere is still very likely to be dominant for language function.

Further confirmatory information is derived from observations during surgery. Figure 4-1 (Penfield and Roberts, 1959) summarizes the results of Dr. Wilder Penfield and his associates in Montreal of stimulation of the brain at surgical operation. Each of these A's indicates the occurrence of an aphasic response to electrical stimulation of the exposed brain. We have shown here only the left hemisphere and the inside of the medial surface of the left hemisphere. You will notice that the A's are grouped to some extent in two areas on the left side—one anteriorly (Broca) and the somewhat more diffuse area at the junction of the temporal, parietal, and occipital lobes (Wernicke).

Figure 4-2 (Penfield and Roberts, 1959). Penfield and his associates have also recorded the result of excision of the brain for the control of epileptic seizures and have mapped out an almost identical area, excision of which leads to at least temporary impairment of language. Again these are left hemispheres.

Figure 4-3 (Russell and Espir, 1961). Similar observations are reported by Russell and Espir of individuals who had wounds during the war. Two charts of the left hemisphere are presented. One indicates those lesions which did produce aphasia; the other, those which did not. In the left hemisphere, the large majority of wounds caused aphasia. Only those quite far forward in the frontal lobe and a few around the fringes did not have that effect.

Figure 4-4 (Russell and Espir, 1961) compares the right hemisphere. Here the majority of the right hemisphere lesions did not produce aphasia. A limited number of wounds on the right did produce aphasia and you notice that three of them were in individuals who were left-handed.

Figure 4-5 (Russell and Espir, 1961) reports the location of the injury of individuals who still were able to understand the spoken word but who had a loss of motor speech. We will come later to the question of the significance of the difference between motor and sensory aphasia. These were patients classified by this group as having "motor aphasia."

Figure 4-6 (Russell and Espir, 1961) portrays lesions which produced a more generalized type of aphasia with a rather complete loss of language function not only for speech but also for comprehension.

Figure 4-7 (Russell and Espir, 1961) summarizes the lesions of a rather select group of individuals with agraphia. In this series it was a group of individuals who had injury along the medial surface of the left hemisphere who were able to speak but who had a specific loss of ability to write.

It is thus quite clear that the major language functions in most individuals are in the left hemisphere, but there is an exception and this exception is in the case of individuals who receive a serious injury of the left side of the brain in childhood prior to the age of approximately 8 years. This is an interesting mystery. In such individuals it is well established that adequate language function can be subserved by the right hemisphere. Many such individuals have had the cortex of the entire left hemisphere removed subsequently for the control of seizures without suffering even a transitory impairment of language. Thus, although in most individuals the language function is subserved primarily by the left hemisphere, the right hemisphere has the capability for this task if this task is forced upon it. Since this is the case, how is it then that we have language disabilities in children? We know that in adults severe and often permanent loss of language is most commonly due to an injury of the left hemisphere, but now we find that there are children whose entire left hemisphere is removed and who still are able to talk quite normally. If that is the case, what is the basis of the language disability of those children who do have language disabilities? There are several possibilities. One is that such children suffer from bilateral lesions involving both hemispheres. A second is that the defect lies in the brain stem or basal ganglia through which information is relayed to the higher brain structures. Still another is that there are genetically or constitutionally determined organizational defects or peculiarities of the brains of such individuals which cause it to be difficult or impossible for them to form the associations or correlations essential to the establishment of language.

In the following sections, I will review our knowledge of the major channels of inflow and outflow of the brain, some observations of the areas within which certain types of correlation appear to be mediated, and some theories as to how the language process may become established and how it may break down.

Figure 4-8 (Penfield and Roberts, 1959) indicates the areas of the surface of the brain having the most direct communication with the outside world. To area 17 (occipital lobe) is relayed visual information. It is displayed on the surface of the brain almost as on a photographic plate—at least with a

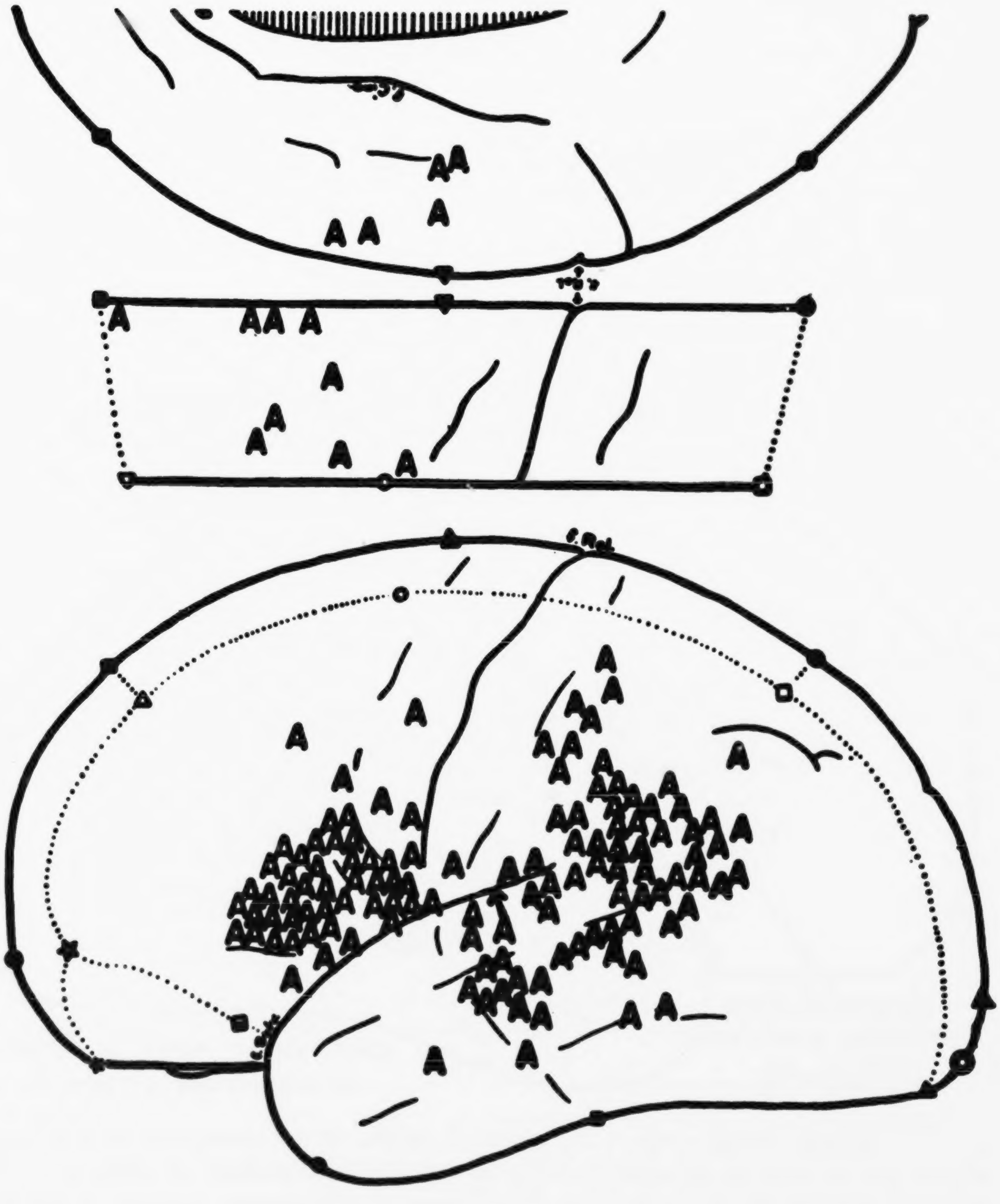
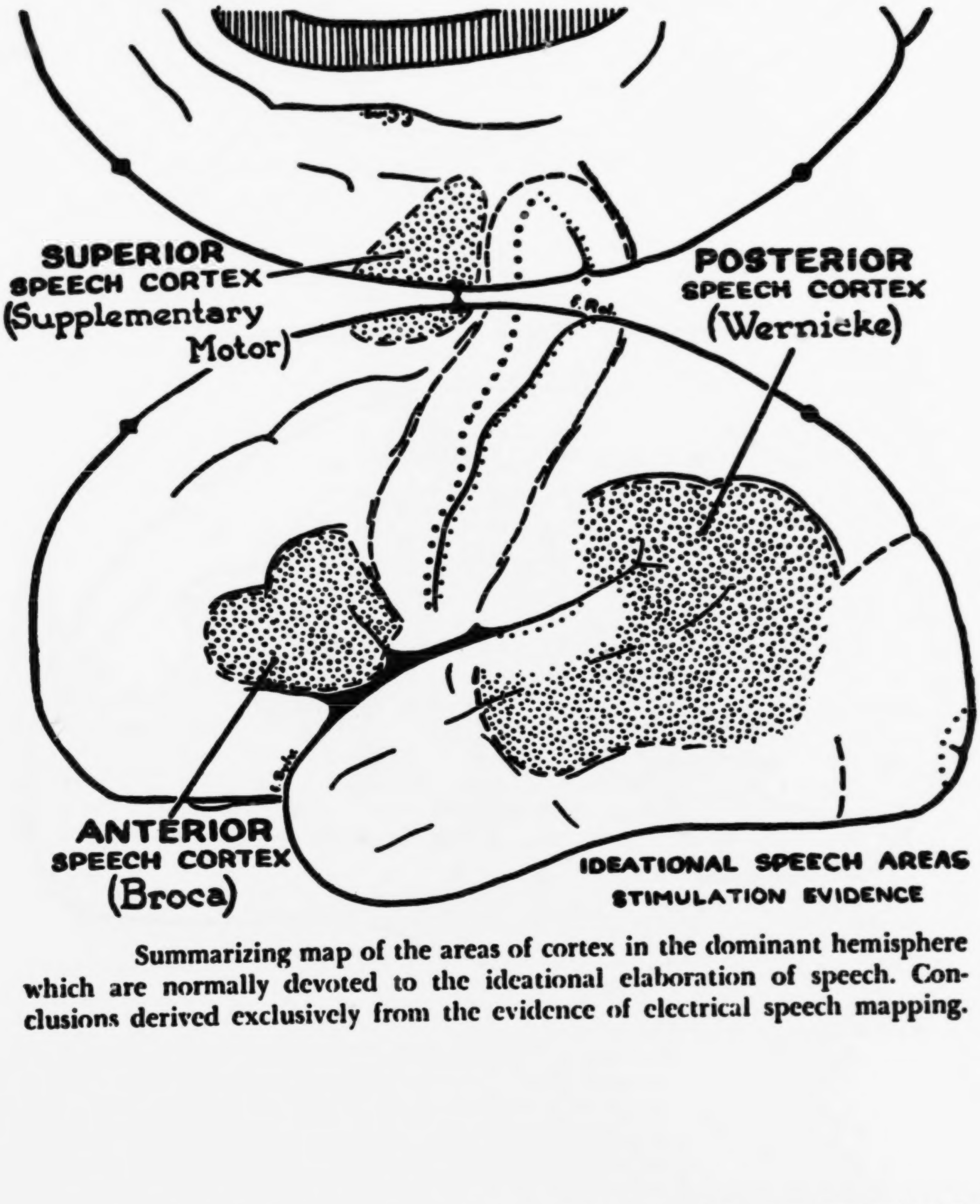
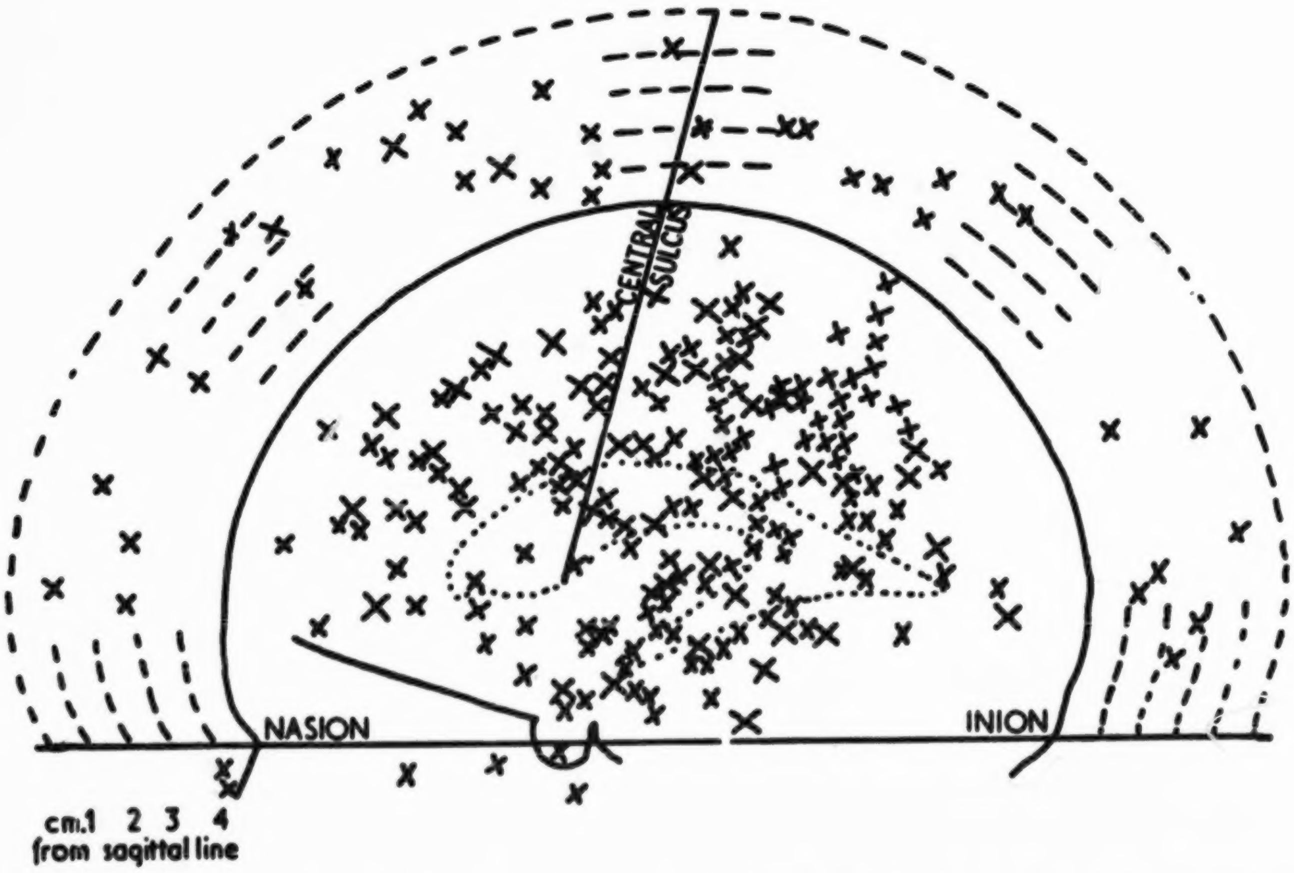


Figure 4-1. Areas of the cortex where electrical stimulation produced an "aphasic" type of response. (Penfield and Roberts, 1959)

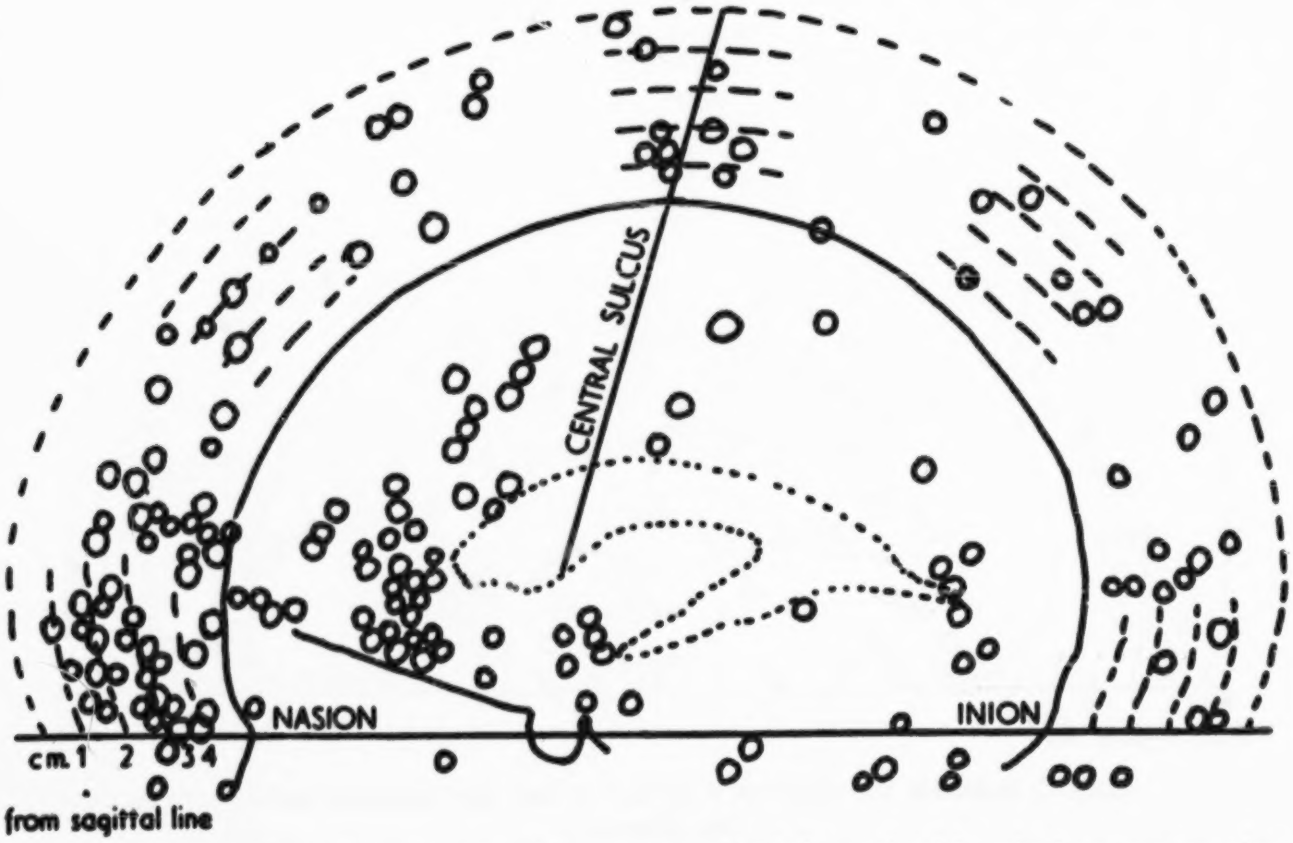

SUPERIOR
SPEECH CORTEX
(Supplementary
Motor)
POSTERIOR
SPEECH CORTEX
(Wernicke)
ANTERIOR
SPEECH CORTEX
(Broca)
IDEATIONAL SPEECH AREAS
STIMULATION EVIDENCE

Summarizing map of the areas of cortex in the dominant hemisphere which are normally devoted to the ideational elaboration of speech. Conclusions derived exclusively from the evidence of electrical speech mapping.

Figure 4-2. Areas of the brain where stimulation or excision produced disturbance of language. (Penfield and Roberts, 1959)

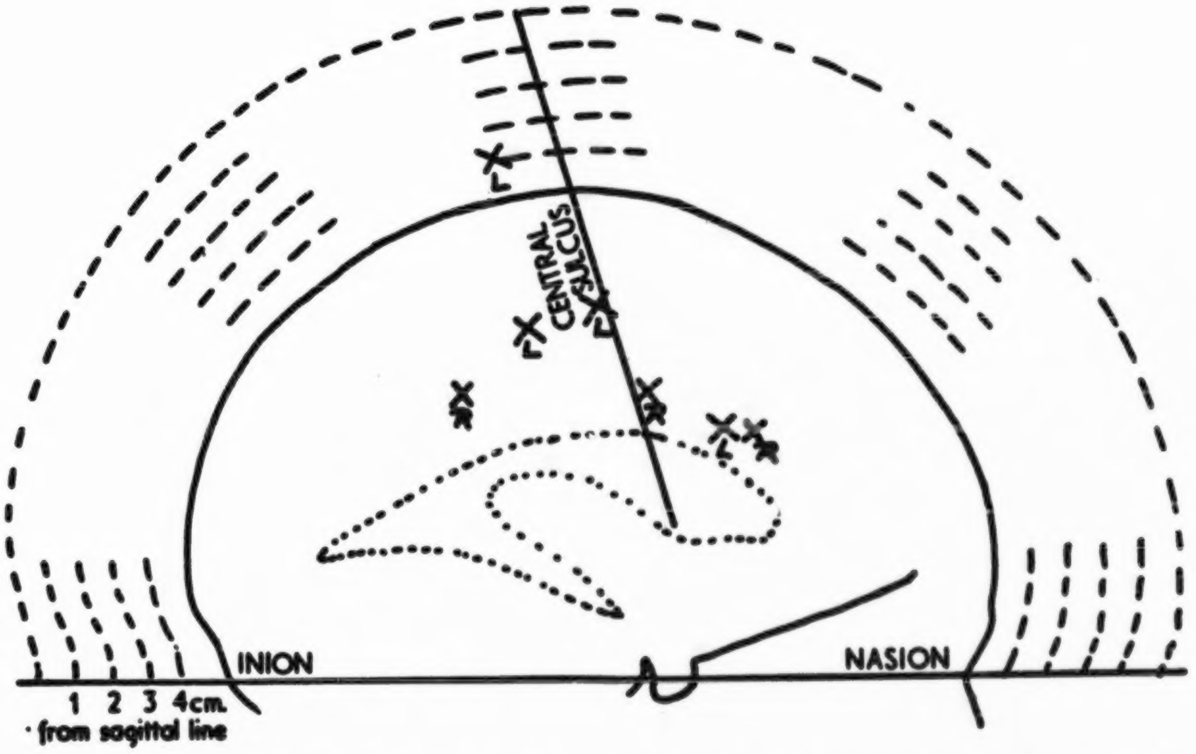

CENTRAL SULCUS
NASION
INION
cm.1 2 3 4
from saqittal line

Skull outline. Each X indicates the centre of a wound in the left cerebral hemisphere causing aphasia.

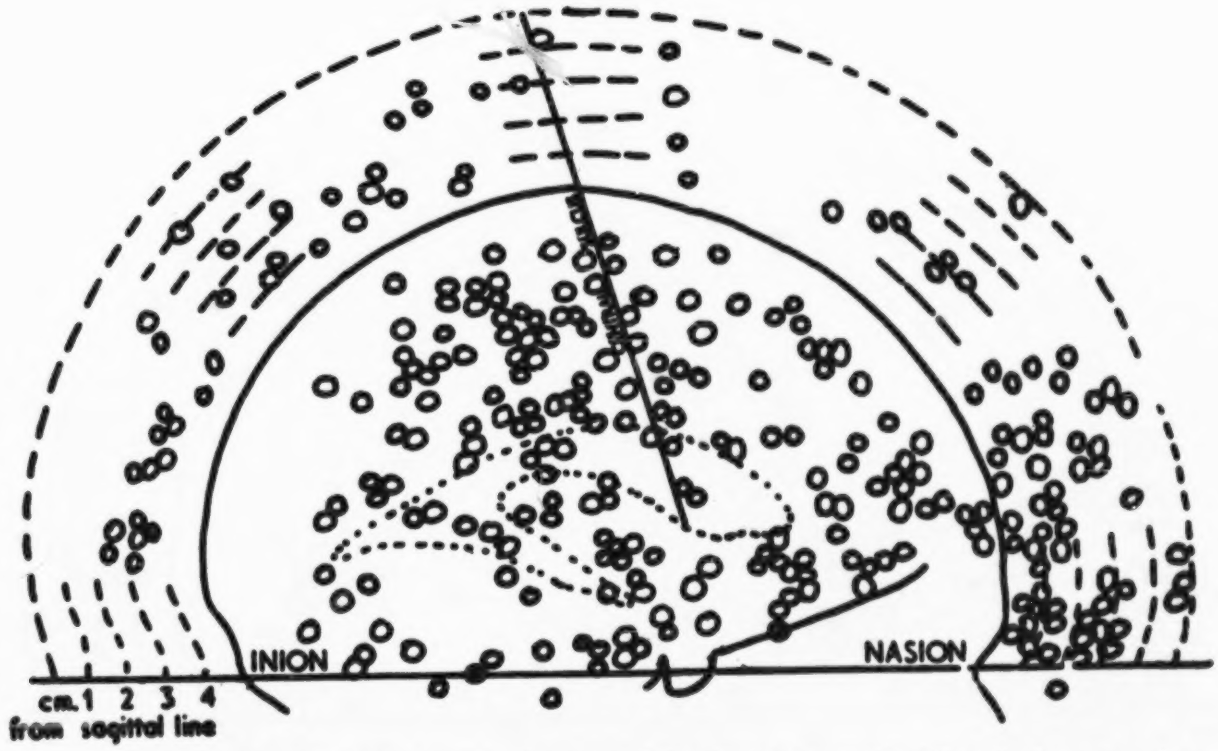

CENTRAL SULCUS
NASION
INION
cm.1 2 3 4
from saqittal line

Each O indicates the centre of a wound in the left cerebral hemisphere not causing aphasia.

Figure 4-3. Aphasia from war wounds (left hemisphere). (Russell and Espir, 1961)


CENTRAL SULCUS
R
L
INION
NASION
1 2 3 4cm.
· from sagittal line

Each X indicates the centre of a wound in the right cerebral hemisphere causing aphasia (R. L. indicate right- and left-handed). Wounds involving the left hemisphere also are excluded.


CENTRAL SULCUS
INION
NASION
cm. 1 2 3 4
from sagittal line

Each O indicates the centre of a wound in the right cerebral hemisphere causing no aphasia.

Figure 4-4. Aphasia from war wounds (right hemisphere). (Russell and Espir, 1961)

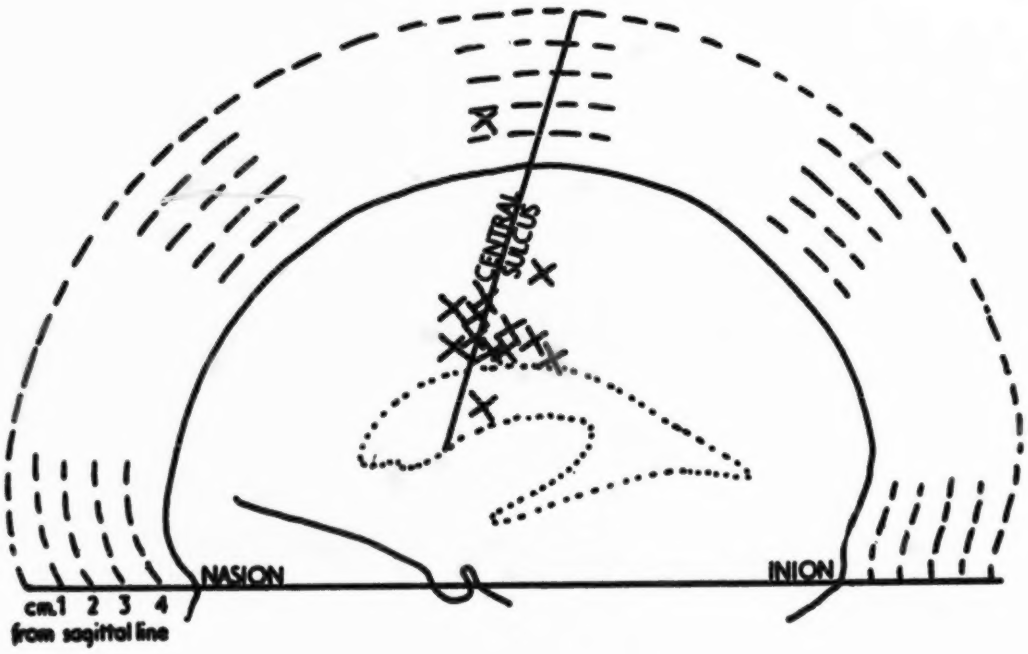

CENTRAL SULCUS
NASION
INION
cm. 1 2 3 4
from sagittal line

Figure 4-5. Small wounds causing "motor" aphasia. (Russell and Espir, 1961)

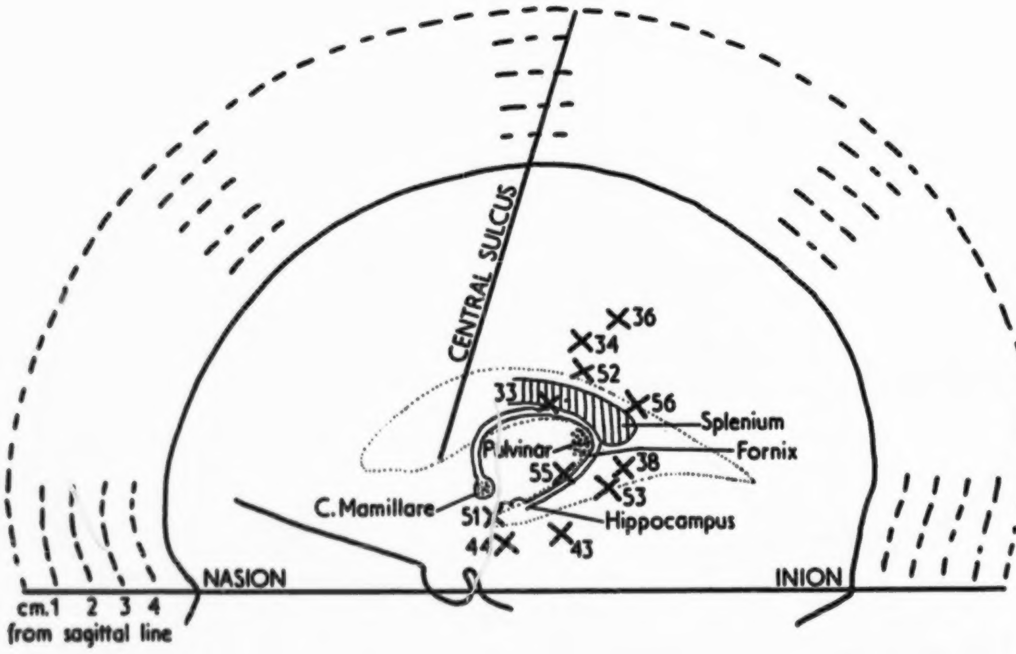

CENTRAL SULCUS
36
34
52
33
56
Splenium
Pulvinar
Fornix
55
38
53
C. Mamillare
51
Hippocampus
44
43
NASION
INION
cm. 1 2 3 4
from sagittal line

Figure 4-6. Small wounds causing "central" aphasia. (Russell and Espir, 1961)

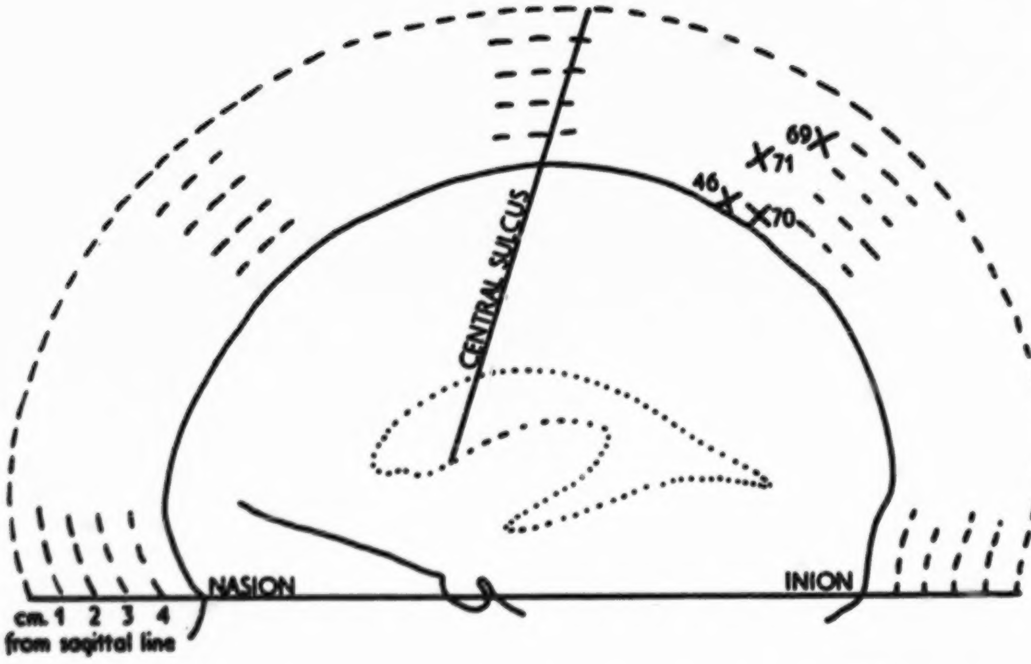

CENTRAL SULCUS
69
71
46
70
NASION
INION
cm. 1 2 3 4
from sagittal line

Figure 4-7. Wounds causing agraphia. (Russell and Espir, 1961)

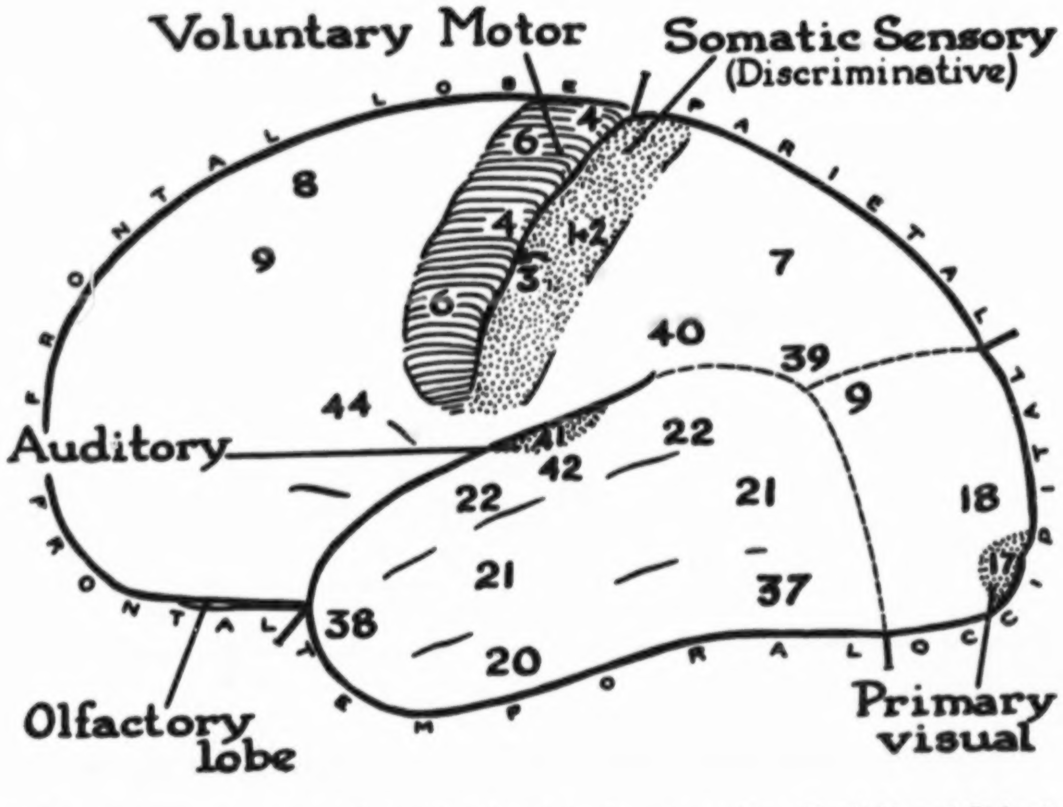

Voluntary Motor
Somatic Sensory
(Discriminative)
FRONTAL LOBE
PARIETAL
OCCIPITAL
TEMPORAL
FRONTAL
4
6
8
9
4
1-2
3
6
7
40
39
19
44
41
22
42
22
21
21
18
17
37
38
20
Auditory
Olfactory lobe
Primary visual

Figure 4-8. Primary areas of information input to human cortex. (Penfield and Roberts, 1959)

spatial arrangement corresponding to what appears in the field of vision.

To area 1, 2 and 3 is relayed somesthetic information from body and skin. Figure 4-9 (Penfield and Roberts, 1959) indicates that these sensations also are displayed on the surface of the brain according to an array corresponding to the spatial orientation of the stimuli.

From areas 4 and 6 originate the voluntary movements. This is the major cortical outflow for movements, and here also, the organization of the cortex (surface) of the brain corresponds to a map of the parts of the body activated. Thus, vision, cutaneous sensation, and motion, all of which involve orientation in space and contact with environment, are associated with a spatially organized display on the surface of the brain. It is as a map against which past and current information can be referred.

The situation for auditory input, which is primarily received in the temporal lobe (area 41) is quite different. Here, spatial relationships have no meaning (actually, it is probably pitch which is spatially distributed on the cortex). The important element in the interpretation of auditory events is not spatial, but temporal. Particularly for language, it is the temporal sequencing of auditory events which is most crucial to meaningful interpretation. It is thus not improbable that the functional organization of the temporal lobe may be quite different from that of the rest of the brain. It will be noted later that parts of this lobe appear to play an essential role in the memory process.

How does the brain interpret the information relayed to its surface through these major channels? Where is this information stored, and how is it correlated? Possibly from studies of some of the simple sensori-motor phenomena we may obtain clues meaningful for the complex. On the following charts I have diagrammed the results of key experiments.

These diagrams represent a crude view of the brain and visual pathways as seen from above. The under surface of the temporal and occipital lobes is shown in a lateral position. Note the organizational pattern of the visual pathways. Information coming from the right half of each eye (coming through the lens from the left field of vision) is relayed to the right hemisphere. Thus each hemisphere receives from both eyes, information coming from the contralateral field of vision.

Figure 4-10 (Myers, R. E., 1962) summarizes experiments indicating the diffuseness with which certain learned patterns irradiate from the primary reception area to other parts of the brain. Monkeys were trained to discriminate between warm and cold using their left hands. Removal of the somesthetic area (1-2-3) does not destroy their ability to perform this task. However, it does prevent them from learning roughness discrimination—a new task with similar discriminatory requirements. Apparently, the previously learned skill has a representation in other parts of the brain and requires a minimum of sensory cues to be activated.

Figure 4-11 (Myers, R. E., 1962) shows the location of a cut of the corpus callosum—a procedure which prevents communication between the two hemispheres and is used to demonstrate the interaction between the two sides of the brain. If a normal animal is trained to do a trick with one hand, it can be shown that he will also know this trick with the other hand. Even a sectioning of the corpus callosum after the trick has been learned with the left hand will not prevent its being known with the right. If, however, the cut is made before the trick is learned with one hand, it has to be learned all over again with the other. Evidently in the normal, unoperated animal, what is learned with one hemisphere is transmitted through the corpus callosal tracts to the other hemisphere, and retained there as a learned pattern useful also for the untrained hand.

Not only are incoming information and learned patterns relayed widely throughout the brain, but also certain interrelated brain areas appear to be essential for the full interpretation of such incoming information. Large areas of the brain called association areas do not have a direct connection with incoming sensory channels, but serve as integrating centers to which information may be relayed from several primary sources. Such association areas are in general less specific in their functions. Bilateral removals may be required to demonstrate a deficit. Figure 4-12 (Pribram, K. H., 1962) shows an area of the posterior temporal lobe, bilateral removal of which causes impairment of visual discrimination. Figure 13 (Stepien, L. S., Cordeau, J. P., and Rasmussen, T., 1960 and Stepien, L. S. and Sierpinski, S., 1961) shows similar areas, removal of which impairs auditory discrimination.

Pathways from these areas flow into the under surface of the temporal lobe. (Figure 4-14—Penfield, W. and Milner, B., 1958 and Milner, B., 1959) The integrity of this area appears to be essential for the establishment of permanent memory traces, and bilateral removal as noted in Figure 4-14 leads to permanent inability to retain some types of new information. It is possible that this structure is a key segment of a recurrent loop through which activity is relayed back to other brain structures and permanently recorded. (Figures 4-15 and 4-16—Ojemann, Robert G., 1966)

An essential feature of most of these more complex discriminatory tasks is the process of association. Events occurring in temporal relationship to each other interact within the brain as a result of this relationship. Possibly subsequent inputs which involve only part of a total pattern may, because of such previously established interactions, now activate the larger pattern. The development of such interactions may be demonstrated by physiological experiment.

Figure 4-17 is from an experiment conducted some years ago by Morrell and Jasper (1956) in a series of animals during the establishment of a conditioned reflex. This is the electroencephalogram during the application of a stroboscopic flashing light. To be noted is the occurrence of rhythmic electrical responses in the occipital lobe. Now in a series of conditioning experiments this flashing light was followed by an electrical shock to the right paw which caused the animals to withdraw the paw. There was thus established over a number of trials a conditioned reflex. Now, when the flashing light was turned on, the animal withdrew his paw without the other stimulus. This series of slides shows the changes in the electroencephalographic response which took place as this animal was developing his conditioned response.

Note that whereas in the first tracing of this experiment the response was only in the occipital area, as the animal developed a relationship between the visual experience and a movement of the limb, a similar rhythmic electrical response is now taking place in the area of the brain through which the motor response is mediated.

After a number of trials, the extent of the activated area is reduced. Especially the occipital rhythm is reduced while the major activity now is in the left motor-sensory area within which the motor response is being mediated. This is a physiological demonstration of some of the processes which take place as a sensory experience is becoming related to or integrated with other functions and activities of the brain. I don't think that it is too much to postulate that every experience that we have, and all of the training and conditioning which occur throughout the lifetime, result in the establishment of activation patterns through which our sensations are interpreted and related to associated information and to the appropriate related responses.

There is one other point in regard to the establishment of these intersensory relationships. I pointed out previously that for the proper appreciation of a visual stimulus, there is required not only the occipital lobe but also the integrity of certain areas within the temporal lobe with which it must interact. I would like to cite an experiment which demonstrates that this interaction takes place most effectively if it is accomplished within a single hemisphere. In the normal animal, the removal of the visual association area on only one side of the brain produces very little deficit. You have to remove both sides in order for an impairment to be elicited. In this experiment (Figure 4-18—Mishkin, Mortimer, 1962) an animal had, first of all, a removal of one occipital lobe and of the ipsilateral visual discrimination area (lesions 1 and 2). Very little impairment of a visual discrimination task resulted. Because of the fact that both the occipital lobe and the temporal lobe of one side were still intact and, interacting in a normal fashion, were capable of adequately interpreting the experience displayed on this occipital lobe. However, when the right temporal lobe and the left occipital lobe were removed in another animal, this animal exhibited a very significant deficit (lesions 1 and 2a). For the animal with such lesions to make an evaluation required an interaction between one occipital lobe and the opposite temporal lobe. This was far more difficult than to use one hemisphere.

If in addition one sections the corpus callosum so that one has an intact occipital pole on one side and a disconnected temporal region on the other, the animal will be very severely impaired. The importance of this is to highlight the fact that integrated activities which take place in a single hemisphere appear to be carried out more effectively than are such activities when they involve an interaction between two hemispheres. Possibly this is the reason why such complicated functions as language become centered in a single hemisphere. If the development of a language capability requires a complex interaction of visual, auditory, and cutaneous information and also an integration with previously encountered experiences, these experiments would suggest that such an integration can be more effectively accomplished within a single hemisphere than if there is required an interaction between the two hemispheres.

The next series of slides reflects certain hypotheses regarding language development which have been presented by Professor Konorski from Warsaw, Poland. Dr. Konorski was a student of Pavlov. He has delved very deeply into problems of language. He is particularly interested in the study of conditioned relationships and conditioned reflexes and possibly much of his analysis of the language function is influenced by this orientation. Therefore, he is particularly concerned with connections between various parts of the brain. The Russians speak of the cortical areas as "analyzers" and Dr. Konorski feels that language develops through a conditioned relationship between these analyzers and certain coding areas within which motor patterns are established.

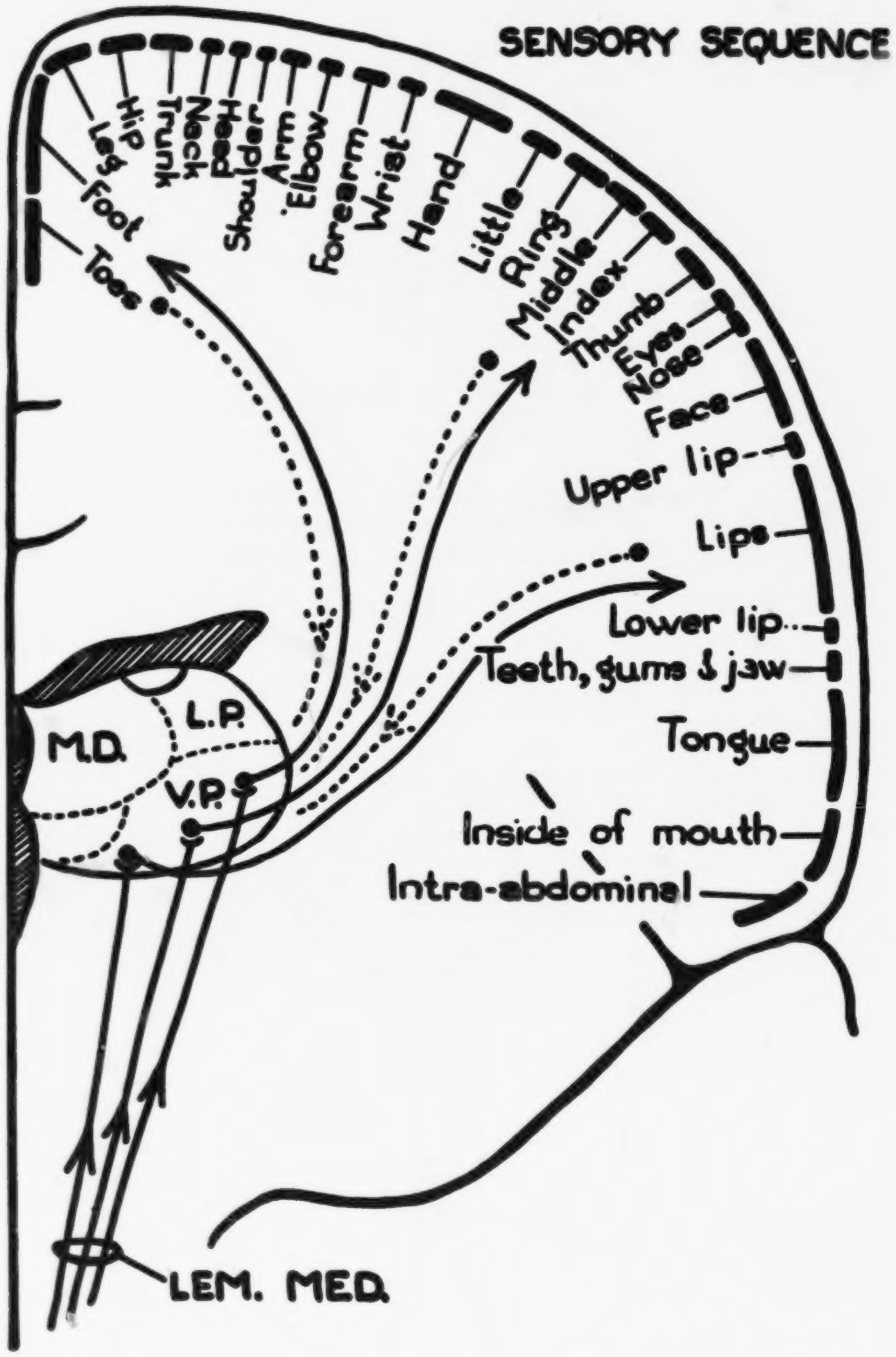

SENSORY SEQUENCE
Toes
Foot
Leg
Hip
Trunk
Neck
Head
Shoulder
Arm
Elbow
Forearm
Wrist
Hand
Little
Ring
Middle
Index
Thumb
Eyes
Nose
Face
Upper lip
Lips
Lower lip
Teeth, gums & jaw
Tongue
Inside of mouth
Intra-abdominal
M.D.
L.P.
V.P.
LEM. MED.

Figure 4-9. Somatic sensation. Cross-section of the left hemisphere along the plane of the postcentral gyrus. The afferent pathway for discriminative somatic sensation is indicated by the unbroken lines coming up, through the medial lemniscus, to the transmitting strip on the postcentral gyrus, and from there on by the broken lines into the centrencephalic circuits of integration. There is, no doubt, close inter-relationship between sensory and motor acivity of the units shown in this figure and the preceding one across the central fissure. (Penfield and Roberts, 1959)

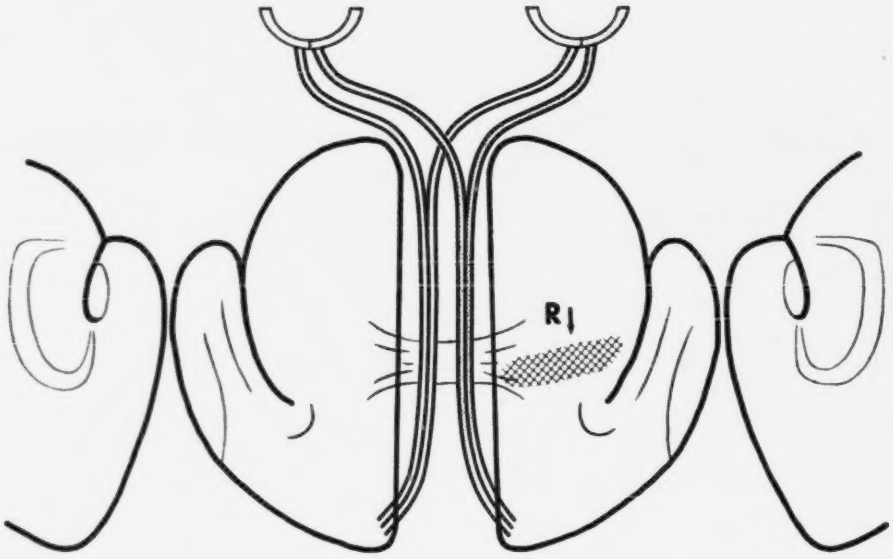


Figure 4-10. Location of lesions producing loss of tactile learning in left hand. Removal (R) of areas 3.1.2. impairs learning new roughness discrimination but leaves previously learned warm-cold. (Myers, R. E., 1962)

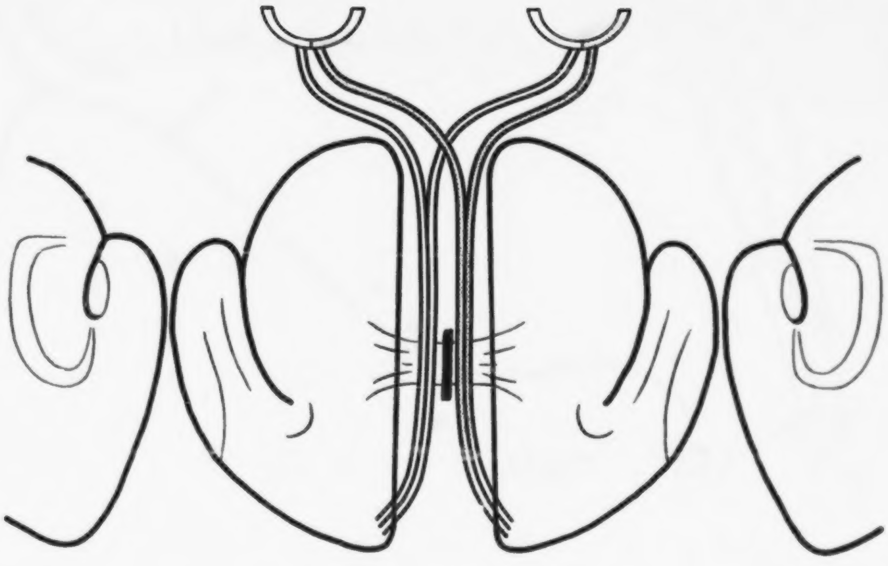


Figure 4-11. Location of a cut of the corpus callosum preventing communication between the two hemispheres.

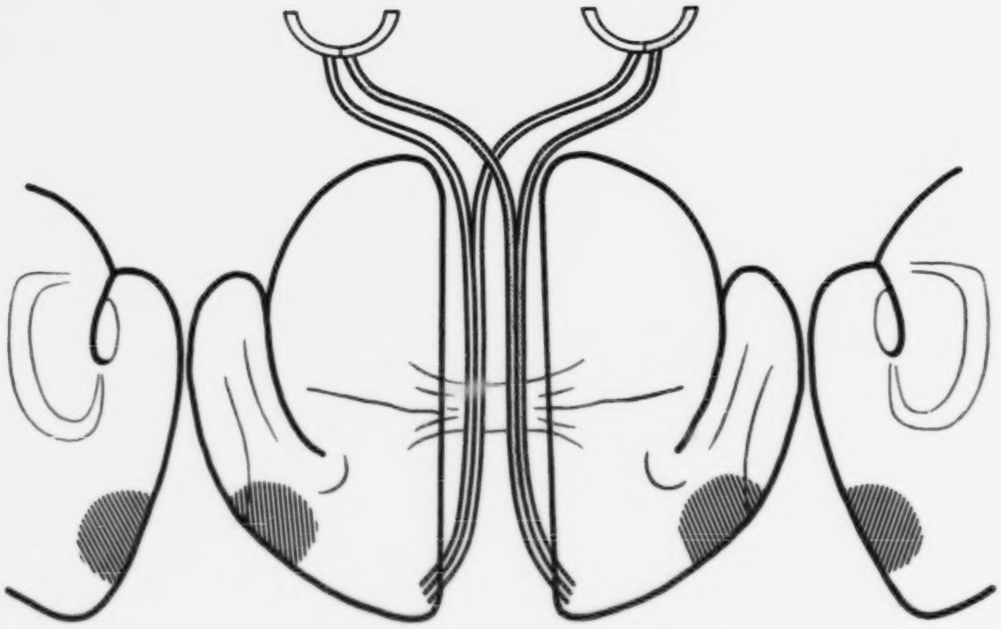


Figure 4-12. Bilateral posterior temporal lobe lesion causing impaired visual discrimination. (Pribram, K. H., 1962)

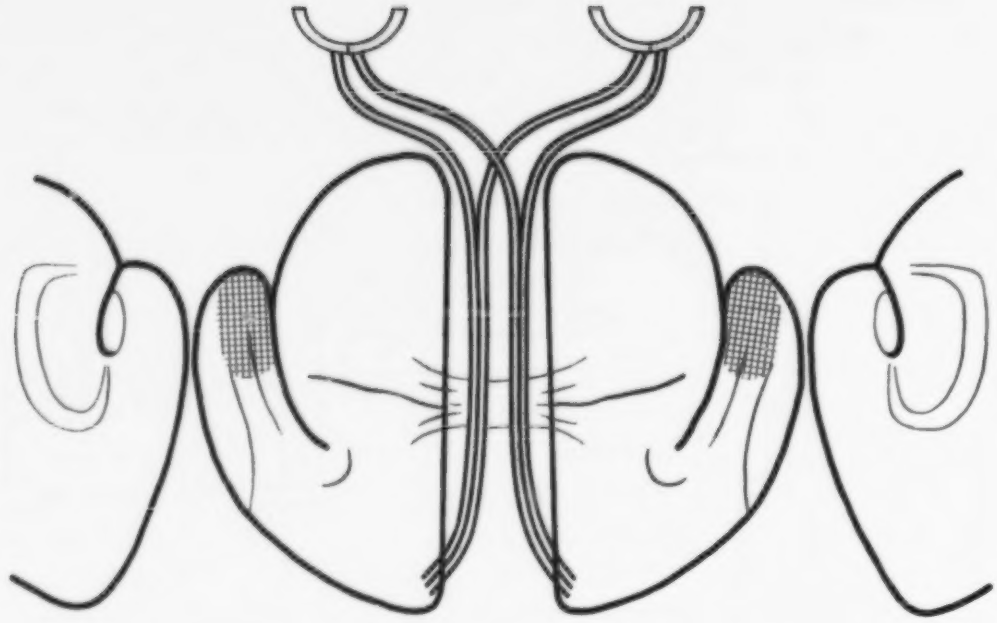


Figure 4-13. Bilateral superior temporal lobe lesion causing inability to differentiate pairs of auditory stimuli. (Stepien, Cordeau, and Rasmussen, 1960; Stepien and Sierpinski, 1961)

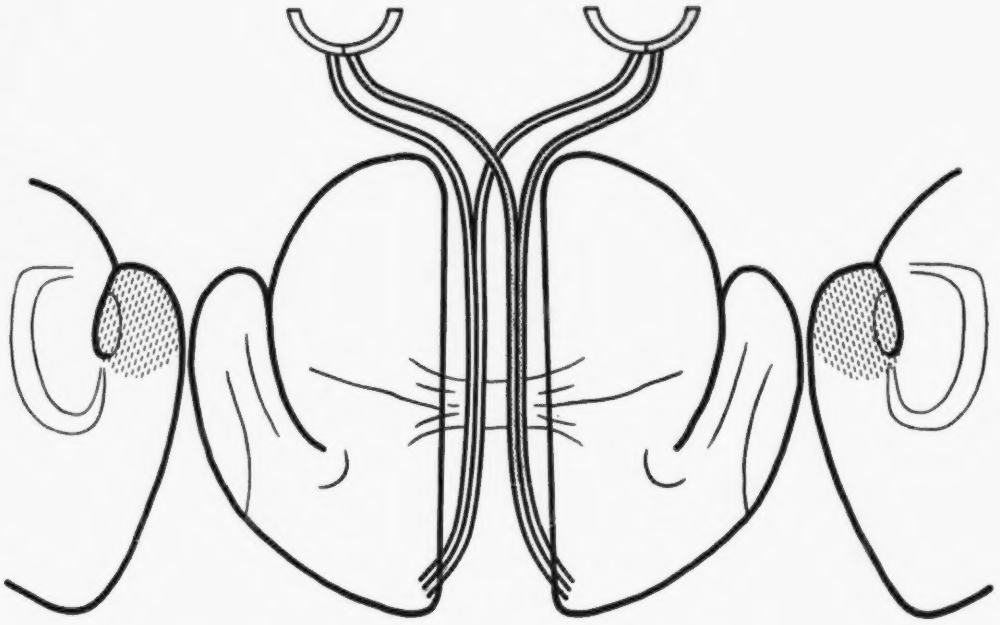


Figure 4-14. Bilateral destruction of medial temporal lobe (uncus, amygdaloid, hippocampus and H. gyrus) producing loss of recent memory. Has not been reproduced in animals even with extensive T-L removals. (Penfield and Milner, 1958; Milner, B., 1959)

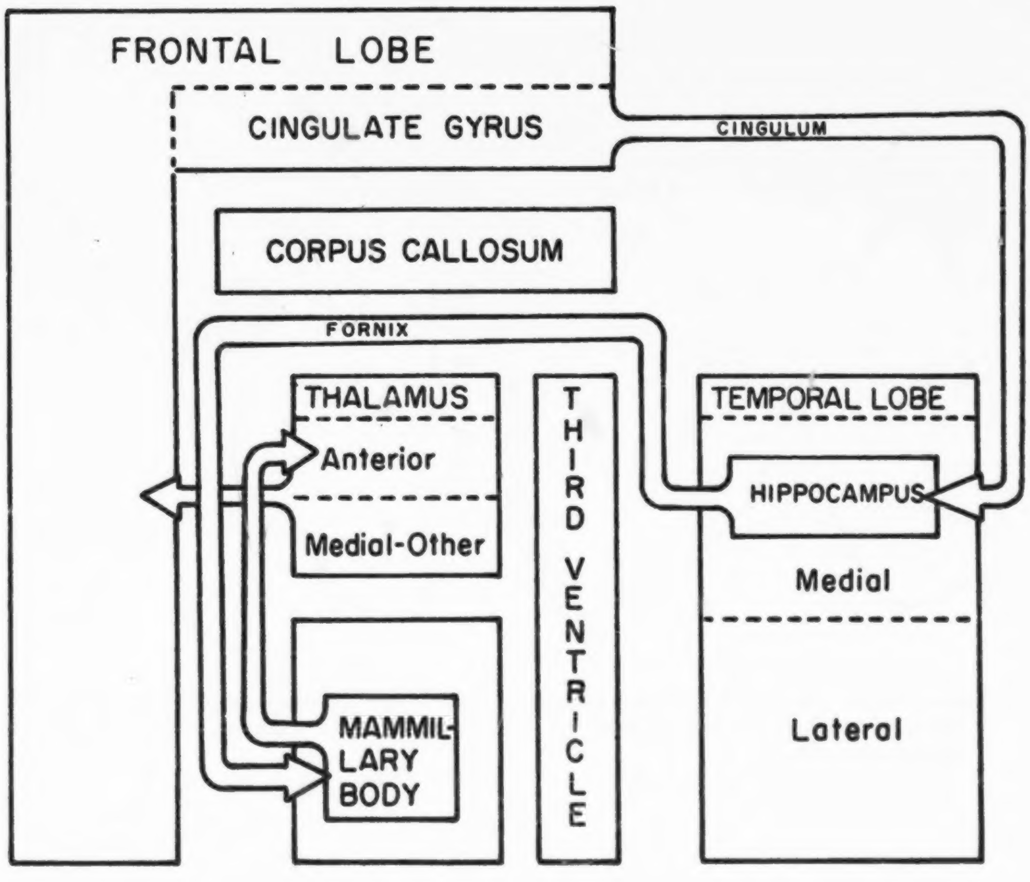

FRONTAL LOBE
CINGULATE GYRUS
CINGULUM
CORPUS CALLOSUM
FORNIX
THALAMUS
Anterior
Medial-Other
MAMMILLARY BODY
THIRD VENTRICLE
TEMPORAL LOBE
HIPPOCAMPUS
Medial
Lateral

Figure 4-15. Schematic diagram of human brain structures and connections thought to be related to general memory function. (Ojemann, R. G., 1966)

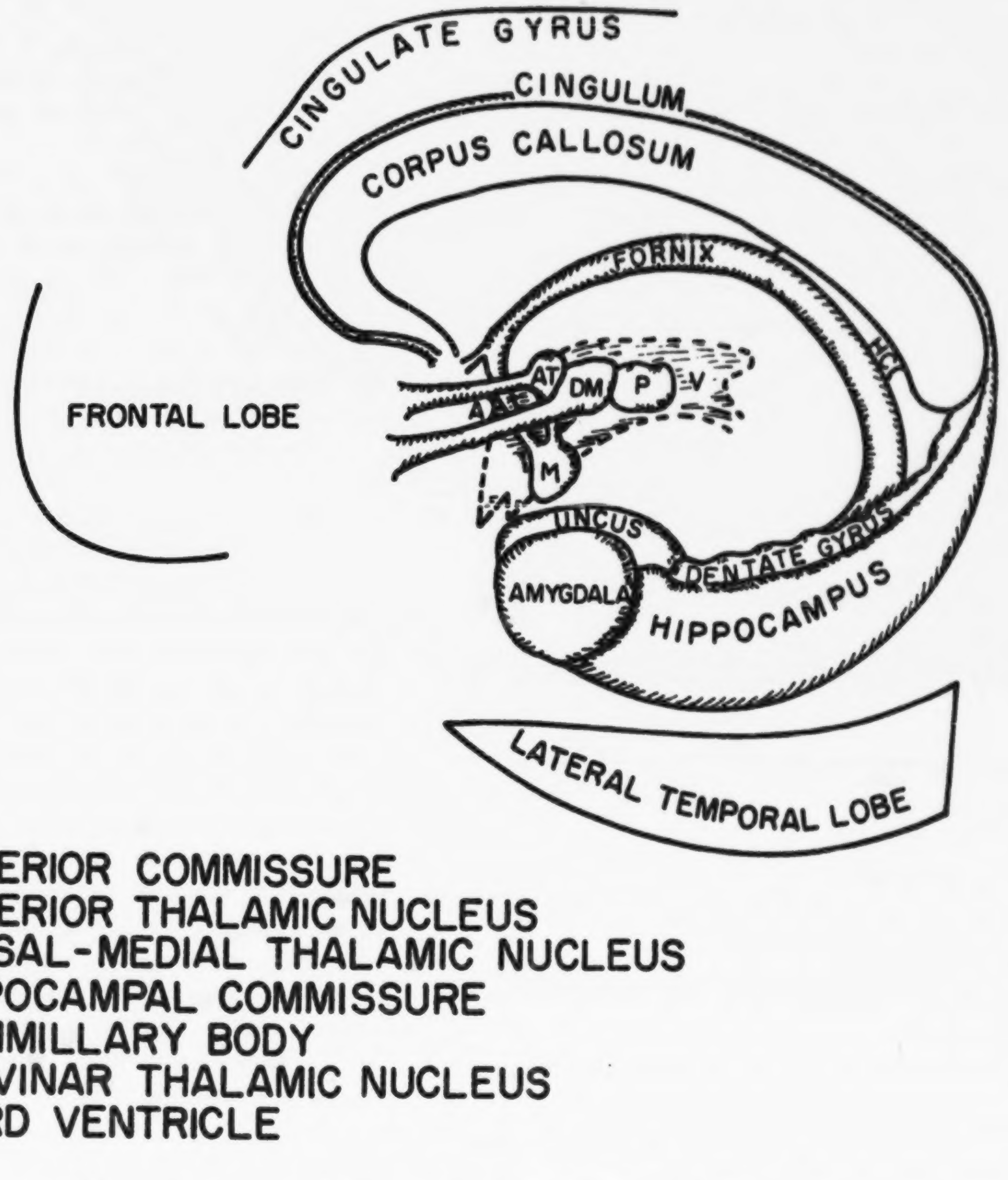

CINGULATE GYRUS
CINGULUM
CORPUS CALLOSUM
FORNIX
HC
AT
DM
P
V
A
M
FRONTAL LOBE
UNCUS
DENTATE GYRUS
AMYGDALA
HIPPOCAMPUS
LATERAL TEMPORAL LOBE
A = ANTERIOR COMMISSURE
AT = ANTERIOR THALAMIC NUCLEUS
DM = DORSAL-MEDIAL THALAMIC NUCLEUS
HC = HIPPOCAMPAL COMMISSURE
M = MAMMILLARY BODY
P = PULVINAR THALAMIC NUCLEUS
V = THIRD VENTRICLE

Figure 4-16. Schematic diagram of lesion in the lateral temporal lobe. (Ojemann, R. G., 1966)

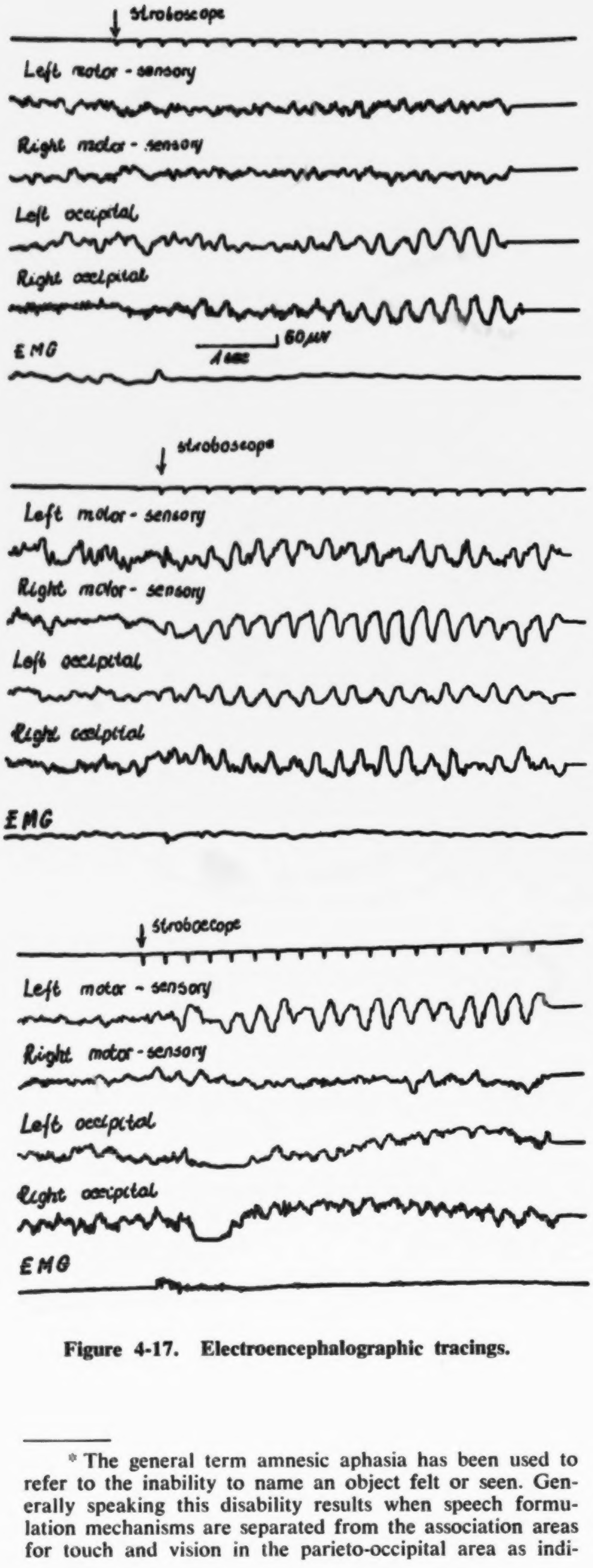


Figure 4-17. Electroencephalographic tracings.

His thesis is that in the early stages of babbling there is established a relationship between the area where sounds are heard and the area where movements of the mouth and tongue are mediated and that the first step in the language process is the development, within a child, of a relationship between hearing and the movements of his vocal organs and the sensation of movement of these organs.

A next step is the mimicking of sounds—the child hears words spoken, he mimics them. The relationship between sound, movement, and the sensation of movement is reinforced. At some point this sound becomes invested with meaning. The investment with meaning requires that an association must be established between the pattern of activation produced by this auditory experience (which may in fact also involve the sense of movement, the pattern of movement, and the memory of the pattern of movement of his own vocal organs) and a visual, tactile or other auditory experience through which that sound has developed some significance.

Dr. Konorski analyzes the disabilities of a series of patients who appear to have impairments resulting from an interruption of pathways connecting the interacting brain areas. The first type he speaks of as audio-verbal aphasia. (Figure 4-19—Konorski, J., 1961). Interruptions between the auditory analyzer in the temporal lobe and the motor engram for speech in the frontal area lead to a condition where persons can understand and can talk but they are not able to repeat a word that they have heard. You speak a word to them. They can't repeat it back.

Figure 4-20 (Konorski, J., 1961), audio-visual aphasia. Another type of aphasia occurs when an individual has an interruption between the cortical area where a sound is analyzed and those areas where the associations with meaning have been developed. These are individuals who can hear a word and may often be able to repeat that word back but they do not comprehend. They are unable to associate the word with its meaning.

Figure 4-21 (Konorski, J., 1961), visuo-verbal. There is a third type, which Konorksi speaks of as visuo-verbal, where patients see an object but they can't name it. In this instance, the connection between the area for visual interpretation and the area for speech has been interrupted.*

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* The general term amnesic aphasia has been used to refer to the inability to name an object felt or seen. Generally speaking this disability results when speech formulation mechanisms are separated from the association areas for touch and vision in the parieto-occipital area as indicated in Figure 21. However there are reported instances in which there was a pure visuo-verbal aphasia—the individual can name an object recognized by touch, but not when seen. Figure 21a (Spreen and Benton, 1966) indicates the location of the lesion on one such case. In this instance, the visual centers of the left occiput were destroyed. In addition, information could not get from the right occiput to the speech center on the left because of a second lesion of the corpus callosum blocking the interhemispheric pathway. No visual information could get to the speech centers of the left hemisphere.

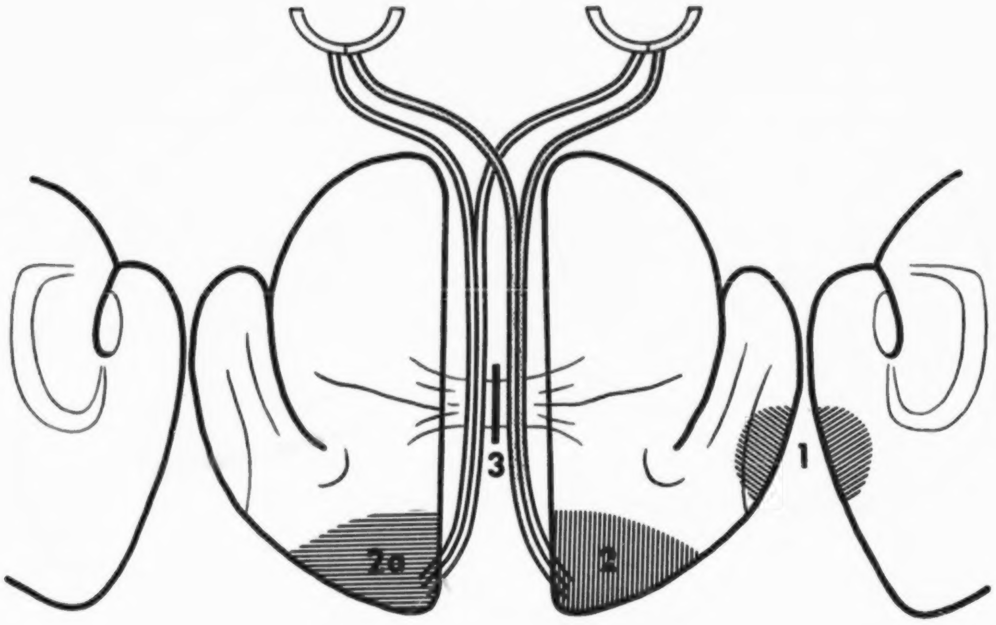

Figure 4-18. Experiment to demonstrate interdependence of occipital and temporal lobe for visual discrimination. 1: Lesion of lateral temporal lobe; 2: Lesion of ipsilateral occiput; 2a: Lesion of contralateral occiput; 3: Section of corpus callosum. 1+2 produces no deficit; 2+2a produces moderate deficit; 1+2a+3 produces severe deficit.

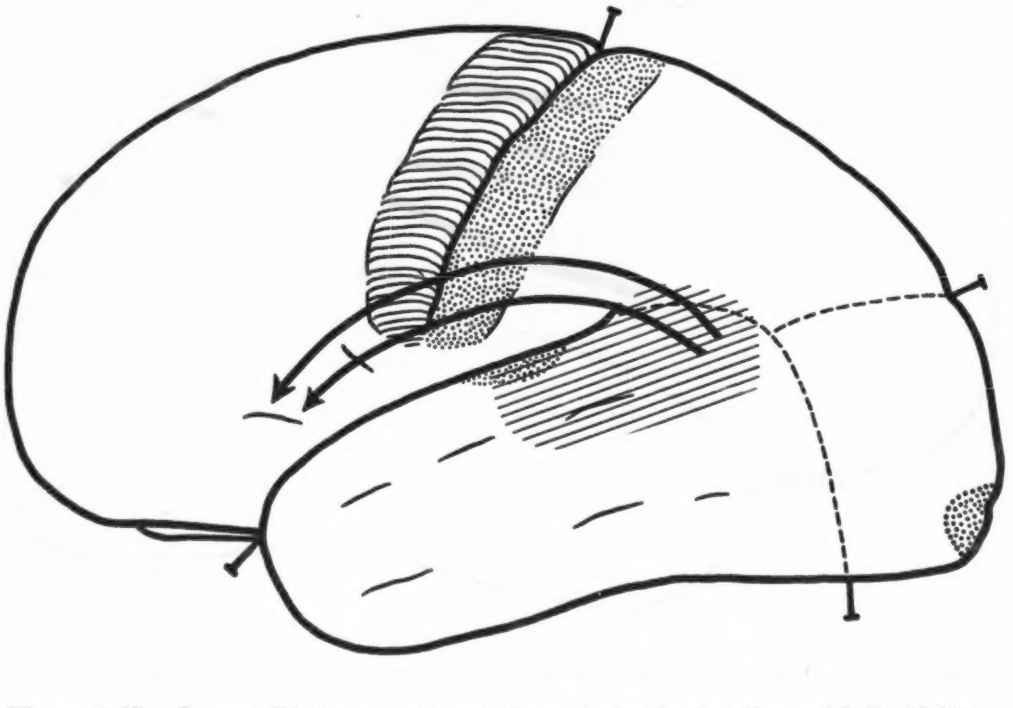

Figure 4-19. Locus of lesions causing audio-verbal aphasia. (Konorski, J., 1961)

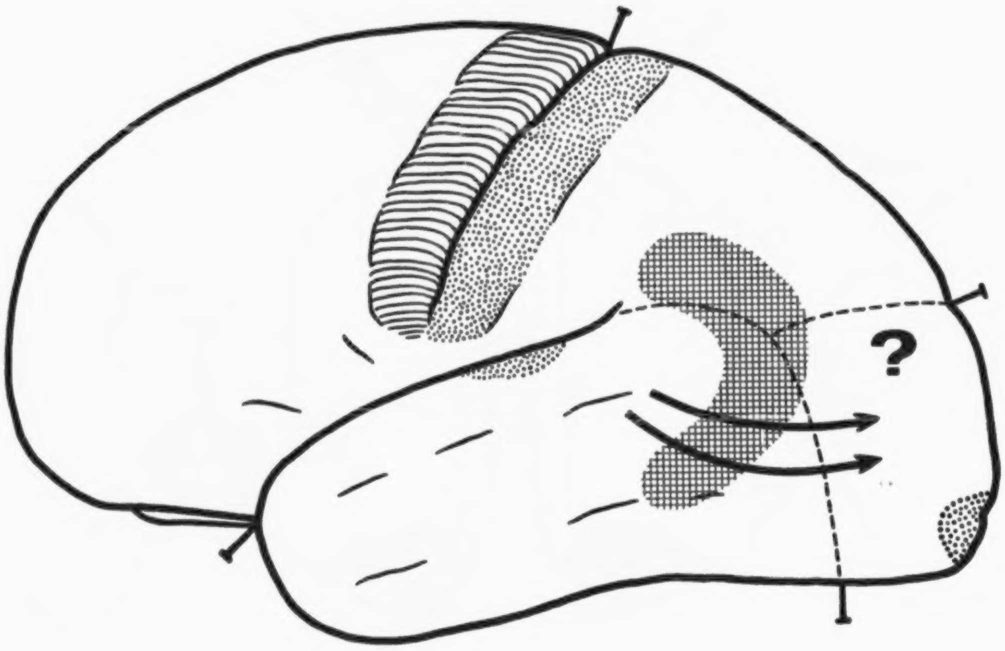

Figure 4-20. Locus of lesion causing audio-visual aphasia. (Konorski, J., 1961)

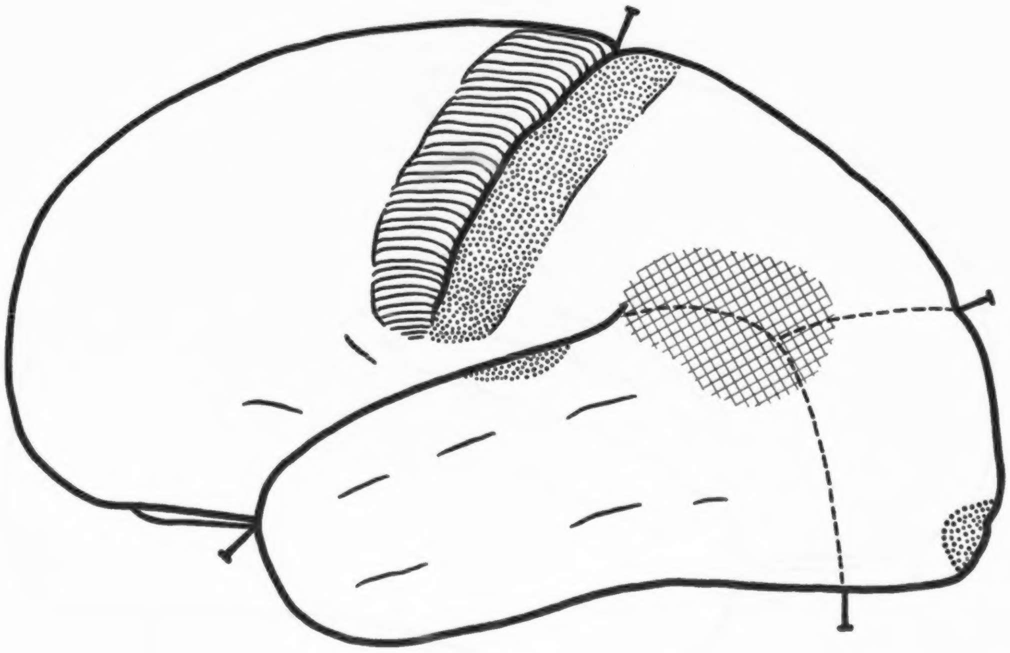

Figure 4-21. Locus of lesion causing visuo-verbal aphasia. (Konorski, J., 1961)

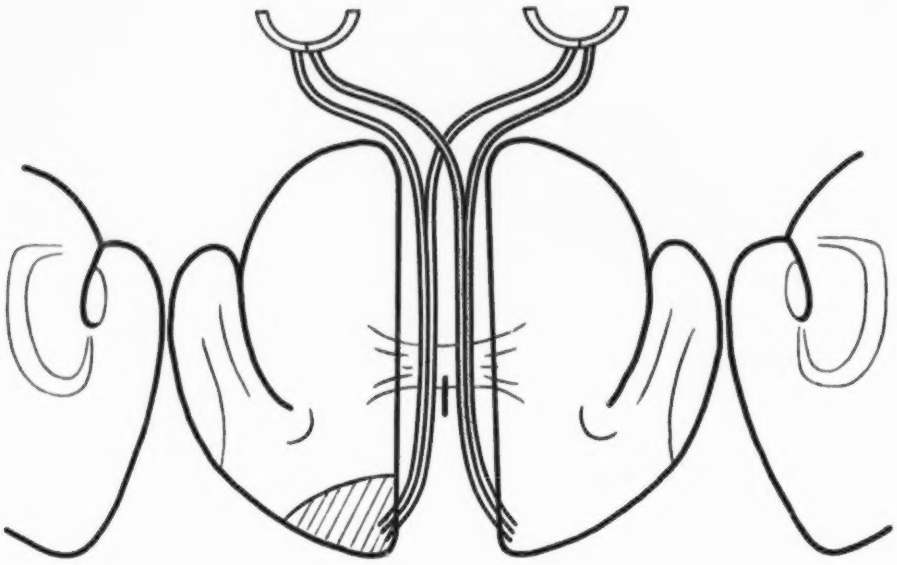

Figure 4-21a. Visual agnosia. Lesion of left occipital lobe and splenium. (Spreen, Benton, and Van Allen, 1966)

Figure 4-22 (Konorski, J., 1961) Kinesthetic-Motor Aphasia. There are two types of injury which interfere with speech movement. The injury in area B produces a disturbance of feedback and motor control because of the interruption of the sensory pathway through which the sense of movement is mediated. Such individuals are likely to have stammering as one manifestation. Injury to area A causes impairment of the motor engram for speech ordinarily spoken of as typical motor aphasia.

Figure 4-23 (Luria, A. R., 1965). Dr. Luria has a slightly different interpretation of forms of aphasia. He is more concerned with the actual loss of cortical tissue than with interruption of intercortical connections. Konorski is preoccupied with intrahemispheric connections. Luria is more concerned with the function of the cortex itself. He describes four main types of aphasia.

Area A—*loss of phonemic hearing.* When this occurs, especially in its minor forms, there will be an inability to distinguish similar phonemes such as p/b, d/t, and v/w. In the more severe forms there is a complete inability to comprehend the spoken word.

Area B—*disturbance of fine, sophisticated articulatory movements.* This, as I have just mentioned, is the so-called kinesthetic area comparable to that of Konorski.

Area C—*destruction of the kinetic schema or skilled movements required for speech.* Destruction of the motor area produces a loss of kinetic pattern, loss of prepositional activities. There is likely to be telegraphic speech.

Area D—*disorder of spatial schemata.* In area D is the most devastating injury of any part of the surface of the left hemisphere. Luria speaks of this as "semantic aphasia," but he emphasizes that it is injury of this area that is particularly prone to lead to disorder of spatial schemata. Interestingly enough he notes particularly disturbances of grammar and in the interpretation of such confusing phrases as "father's brother" vs. "brother's father." Such individuals are likely to have severe problems in orientation and spatial discrimination. Area D is an area of interaction of visual, auditory and kinesthetic events. Lesions of this area in adults are those most prone also to produce impairment of intellectual performance.

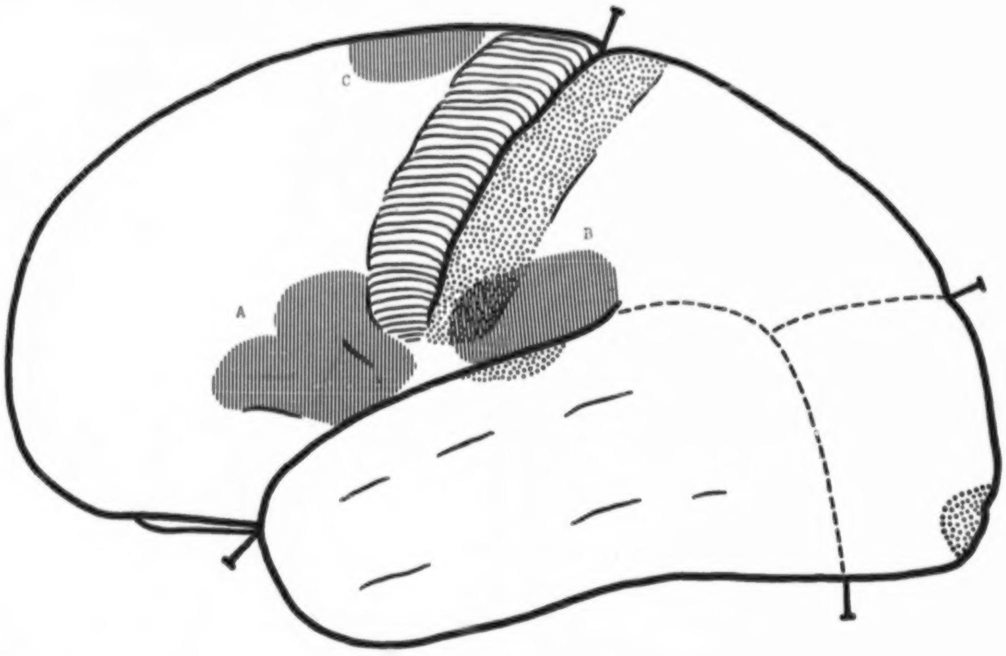

Figure 4-22. Lesions causing "kinesthetic-motor aphasia." (Konorski, J., 1961)

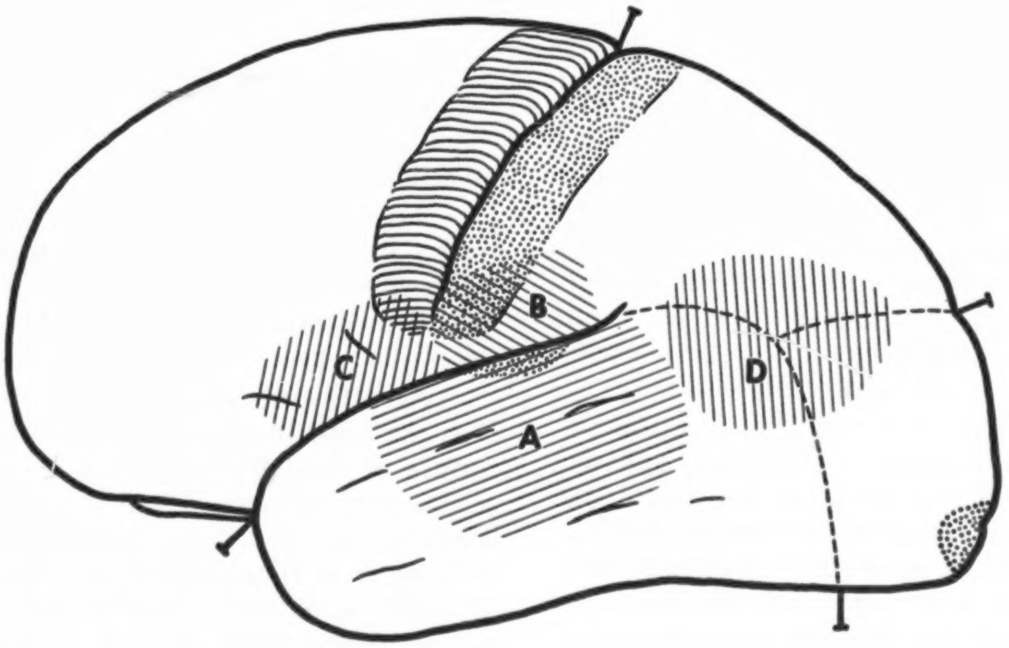

Figure 4-23. Schema of A. R. Luria. A: acoustic; B: afferent; C: efferent; D: semantic.

Figure 4-24 is Luria's graph showing the frequency with which there is impairment of phonemic perception in lesions of various areas of the cortex. It accentuates the fact that phonemic perception is most severely involved in lesions of the superior temporal region.

Although we have been speaking of the adult aphasic, I wonder how many of these manifestations may in fact also occur in the child with a language disability. I believe we do see in children disabilities which resemble those which have been described by these students of the adult aphasic.

It should be noted that experienced observers, for example, Hildred Schuell (1964), who has had tremendous close and intimate experience with large numbers of aphasics, finds difficulties in pigeonholing their cases as sharply as might be expected from the analyses which I have described. A possible explanation is that people like Konorski, Luria, and Geschwind (1965)—whose reports show many similarities of approach—are looking for the isolated patient with a clear-cut limited lesion who will illustrate a theoretical concept. However, most observers agree that there are certain aspects of the language function that are injured or impaired no matter where the lesion is within the speech areas of the dominant hemisphere. Common among these is the inability to recognize and to recall a word. It would appear that the pattern for a word is laid down very extensively throughout this area of the brain.

To recall a word is evidently a difficult task. Possibly it requires that a certain pattern be reactivated. When any portion of this complex mechanism is damaged, this particular capability seems to be lost most strikingly. It is this observation, I think, which has led Hildred Schuell to emphasize that there is a language function *per se* which is disturbed wherever the lesion is located. The pattern differs depending upon an additional overlay of specialized deficits which relate to the specific area of the brain where the lesion is located.

The other question which I would like to discuss is, "what is the essential difference between the functions of the left and the right hemisphere?"

Figure 4-25 (Penfield and Roberts, 1959). I have failed to mention earlier that there are evidences that the right hemisphere also has its own, unique, and specialized function. Thus, injury of the temporoparietal area of the right side may produce a disturbance of spatial perception, awareness of body scheme and spatial relationship. This lesion corresponds to that on the left producing the most severe disruption of language and of its associated thought processes. This raises the possibility that the right hemisphere assumes a dominant role for spatial relationship and the left hemisphere assumes a dominant role for temporal relationship. If one assumes that for the language function it is temporal relationships which are most crucial, then it would be natural for the language function to be developed in the left hemisphere.

Figure 4-26 (Subczynski, J., 1961) indicates the location of injuries of the dominant hemisphere which lead to disturbances of rhythmic pattern reproduction. These findings support the view that the left hemisphere is essential for the appreciation of temporal relationships.

Figure 4-27 (Efron, R., 1965) summarizes observations of patients with diverse brain lesions. Dr. Robert Efron tested a series of such patients for their ability to recognize temporal relationships. He tested for ability to appreciate the temporal order of two flashing lights of different color and of two sounds of different pitch. Here also it is lesions on the left side of the brain that lead to impairment. When the lesion is in the posterior region (B), there results a sensory type of aphasia and impairment of visual temporal sequence. When the lesion is more anterior (A), there results a motor type of aphasia and impairment of auditory temporal sequence. Such impairments were not seen by him in comparable injuries of the right hemisphere.

There are others, however, who have another possible explanation for the relationship between the left hemisphere and speech. Dr. Brenda Milner and her associates in Montreal have postulated that the left hemisphere is primarily concerned with symbols and with the integrative functions which are required in the relationship between symbol and object. Kimura (1966) conducted a series of experiments in which a visual display has been presented either in the right half or in the left half of the visual field. Verbal and nonverbal stimuli were tachistoscopically presented to normal subjects. Successive random presentations to either the left or the right visual half-field were made. Letters were more accurately identified in the right visual field but certain nonalphabetical stimuli were more accurately enumerated when they appeared in the left field. The author concluded that the left posterior part of the brain has an important role in the identification of verbal-conceptual forms, and the corresponding area of the right side of the brain has other functions for registering nonverbal stimuli.

In summary, I would like again to emphasize that the disturbances which I have described in adult aphasics probably have their counterpart in the young in a very much modified and distorted form. I have pointed out that one of the unique features of the language function is that it is centered in one

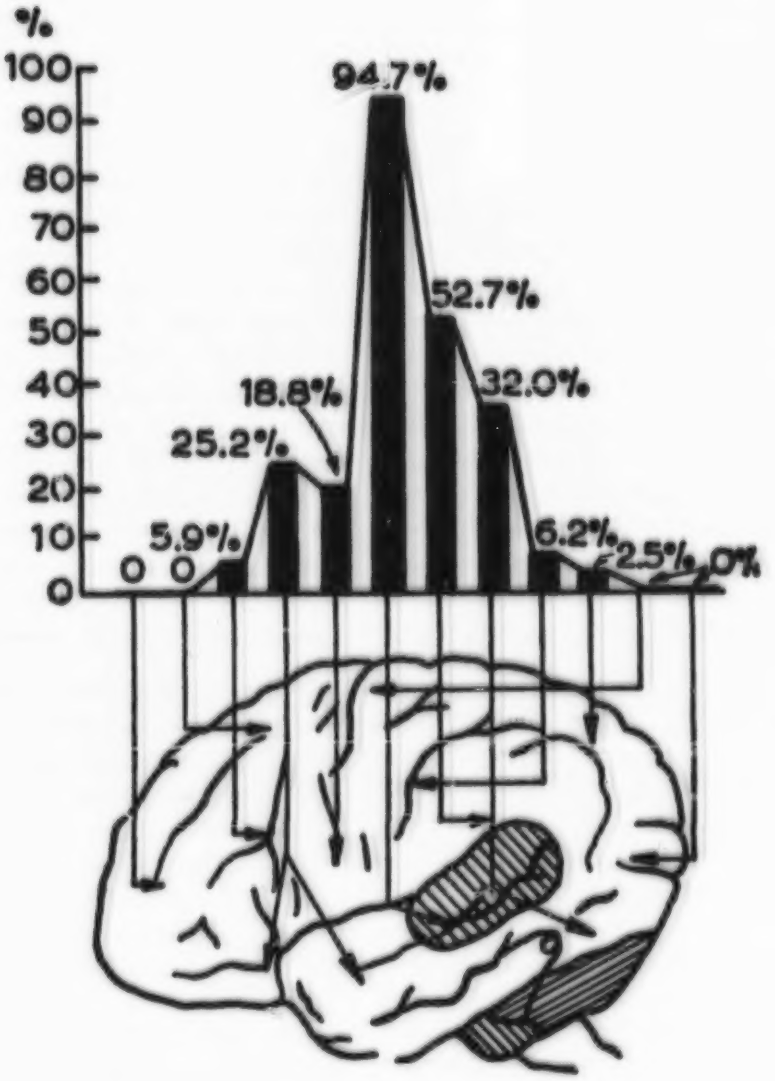

Figure 4-24. Distribution of frequency of cases with impaired phonematic perception, according to the localization of the cerebral lesion. (Luria, A. R., 1965)

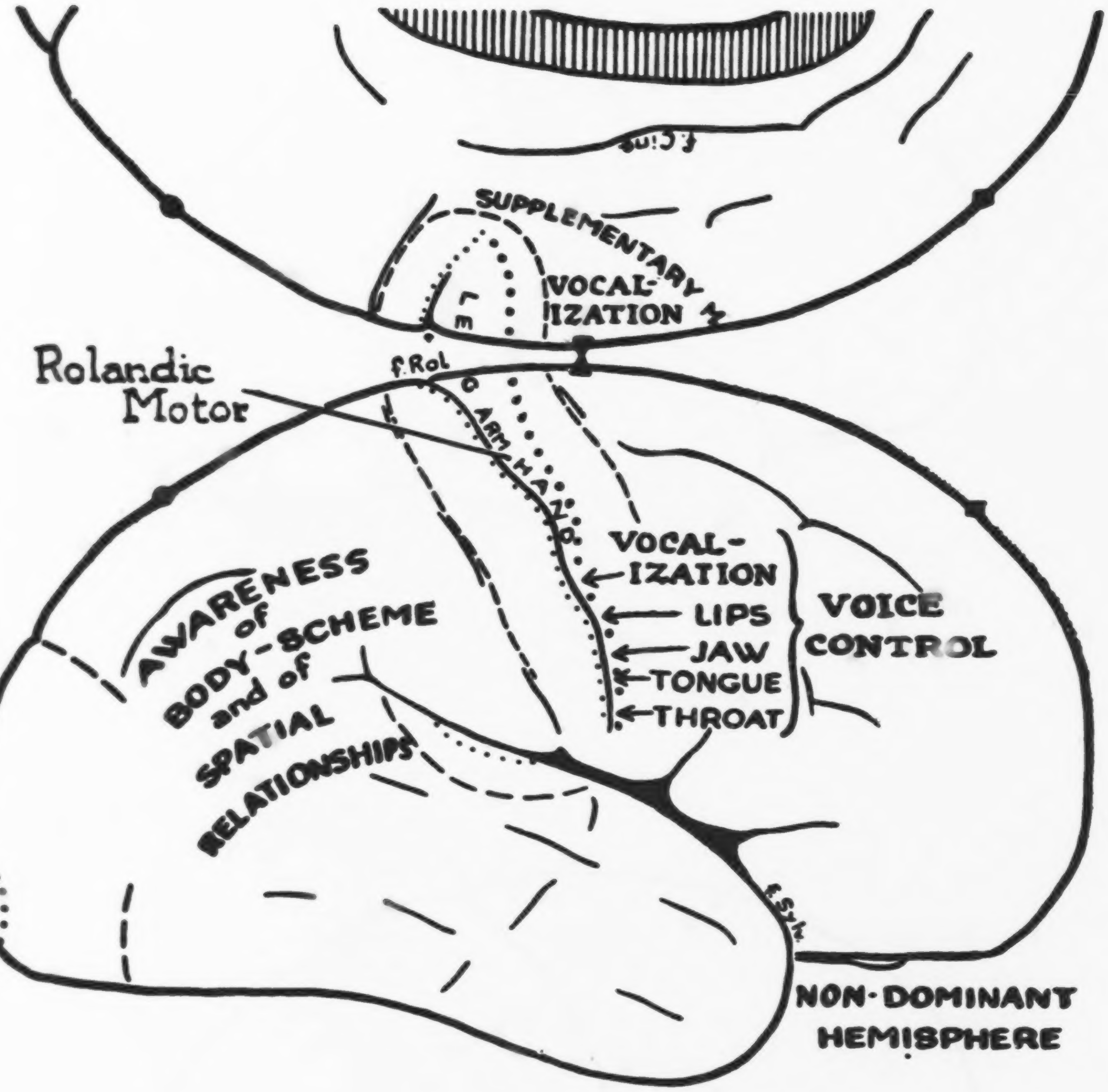
f.Cing
SUPPLEMENTARY
VOCAL-
IZATION
L
E
f.Rol
Rolandic
Motor
G
ARM
HAND
VOCAL-
IZATION
LIPS
JAW
TONGUE
THROAT
VOICE
CONTROL
AWARENESS
of
BODY-SCHEME
and of
SPATIAL
RELATIONSHIPS
f.Syl.
NON-DOMINANT
HEMISPHERE

Figure 4-25. Area of right hemisphere injury impairing body image and spatial orientation. Areas devoted to the motor mechanisms of speech in the minor or non-dominant hemisphere are similar to those shown for the other side. Vocalization is produced by stimulation on this side as on the other. A lesion in the voice control area produces dysarthria similarly. Removal of the zone, which would be the posterior cortical speech area of Wernicke in the dominant hemisphere, produces the apractognosic syndrome. (Hecaen, Penfield, Bertrand, Malmo, 1956; Penfield and Roberts, 1959)

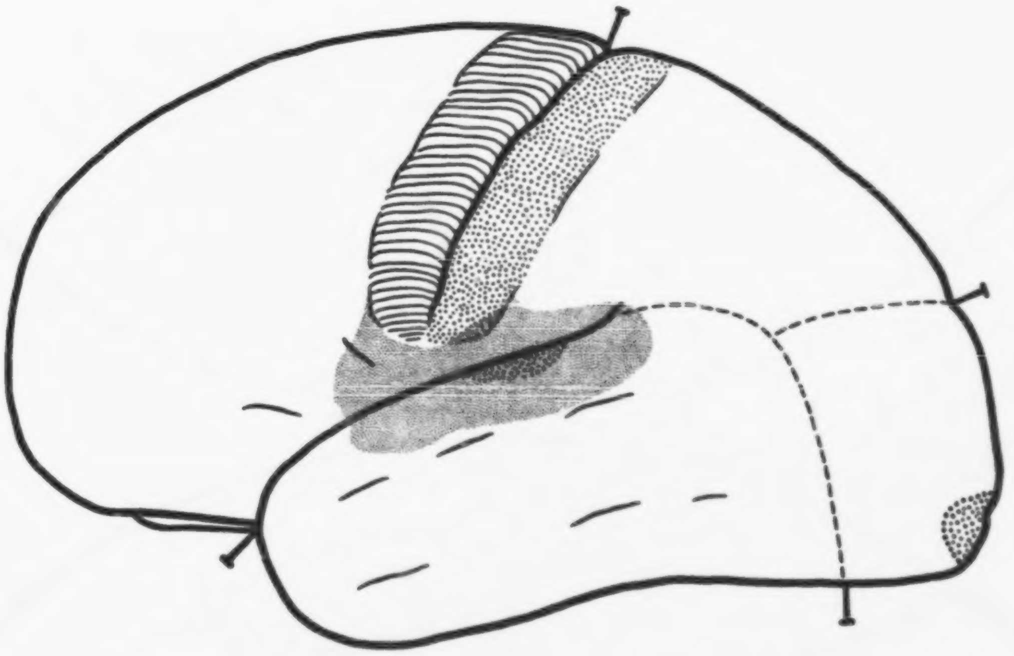

Figure 4-26. Locus of lesions producing loss of discrimination of rhythms. (Subczynski, J., 1961)

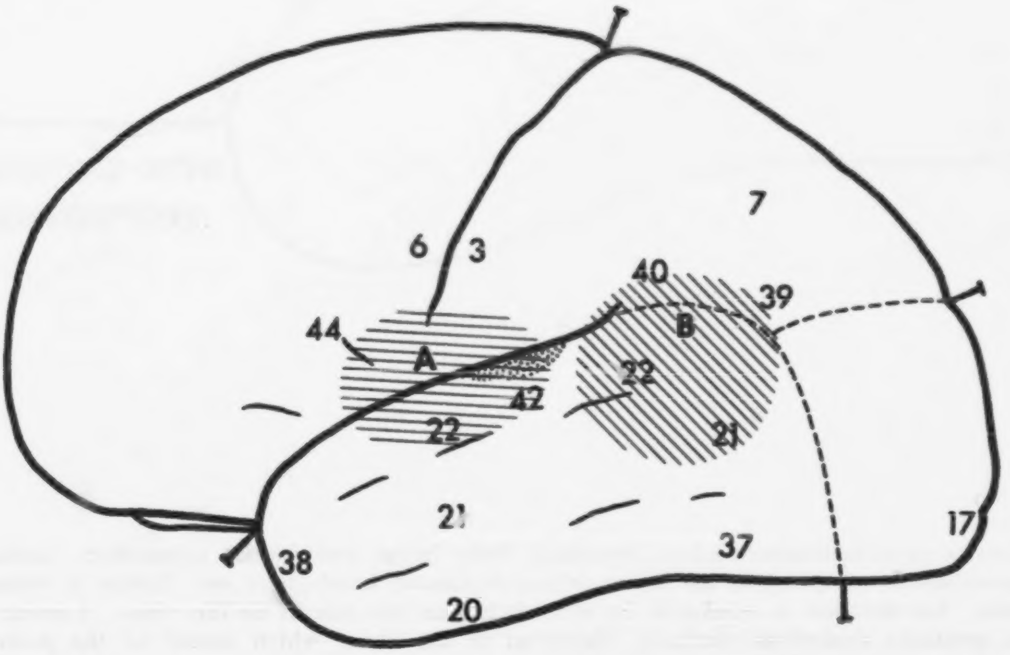
6
3
7
40
39
44
A
B
22
42
22
21
21
37
17
38
20

Figure 4-27. Approximate locus of lesions producing (A) "motor" aphasia and impairment of auditory temporal sequence; (B) "sensory" aphasia and impairment of visual temporal sequence. (Efron, R., 1965)

hemisphere. I have described experiments to show that when an integrative function must involve both hemispheres, it is more difficult than when it can be accomplished within a single hemisphere. These experiments provide an explanation for the lateralization of language function within a single hemisphere.

In seeking some fundamental functional difference as an explanation for the consistency with which the left hemisphere subserves the language function, two possibilities have been presented. The first emphasizes that language is concerned primarily with auditory events, and that for audition, a precise appreciation and analysis of temporal sequences is paramount. Possibly the left hemisphere is more effective in such analysis. Other perceptual processes involving visual and kinesthetic inputs involve spatial rather than temporal relationships. There is some evidence that the right hemisphere is more effective for these.

A second explanation assumes that the differences between right and left hemisphere functions relate to differences between the recognition of learned symbols as opposed to nonmeaningful objects. Further studies will be required to further clarify these important fundamental issues. The work which Dr. Orton did so many years ago was well recognized at the time. These recent experiments serve even more to accentuate how far ahead of his time he was and how perceptive were his comments regarding cerebral dominance and dyslexia.

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B. *An Outline of the Problem of Aphasia in Adults.* A second, somewhat different point of view, but not at all at variance with that of Dr. Masland, is presented by Dr. Hildred Schuell. Her special concerns in clinical work and follow-up study have been centered in adult aphasics, specifically those who are referred within the Veterans Administration.

A landmark in textual treatment of the subject was the book with which she collaborated with two colleagues on *Aphasia in Adults* (Schuell, Jenkins, and Jimenez-Pabon, New York: Hoeber, 1964). Here is to be found an eclectic historical treatment of the topic, the work of the group in the development and use of an extensive battery of descriptive tests, a presentation of the levels of quantitative aphasia, and a critique of the field. Schuell infers from her experience that regardless of a possible site of lesion, there is a specific language function that is disturbed (commonly inability to recognize and recall a word), even though in her series many persons are still able to speak.

In gracious response to the Subcommittee's request, Dr. Schuell undertook to rethink her experience and her position and sent in an outline which in effect could be a revision of her book. Throughout this effort is a running critique of her understanding of current theories, attitudes, and practices relative to the general topic of "aphasia in adults." With the thought that it would be presumptuous to condense further what is already a condensation, it was believed best to reproduce the entire outline. It should offer a refreshing experience for those familiar with the field, and an extensive overview for those who are not. Here is Dr. Schuell's oultine.

APHASIA IN ADULTS

by Hildred Schuell, Ph. D.

I Scope of Problem
- A. Aphasia is a many-faceted problem which must be studied in more than one contextual framework.
  - 1. This complexity accounts for diversity of approaches found among investigators.
  - 2. Diversity of approach not only heuristic but necessary, since various approaches require different kinds of backgrounds, competencies, and insights.
  - 3. Complexity of problem imposes upon investigators and clinicians alike necessity for communication across disciplines.
  - 4. Necessity for interdisciplinary approach has been recognized in several symposiums, conferences, and meetings.
    - a. Research Seminar, sponsored by the Committee on Linguistics and Psychology, Social Science Research Council, Boston, 1957 (See Osgood, C. E., and Miron, M. S., *Approaches to the Study of Aphasia*, Univ. Illinois Press, Urbana, 1963).
    - b. Symposium on Disorders of Language, sponsored by the Ciba Foundation, London, 1963 (See de Reuck, A. V. S., and O'Connor, M., *Disorders of Language*, Churchill, London, 1964).
    - c. Conference on Brain Mechanisms Underlying Language, sponsored by NINDB, Princeton, 1965.
    - d. Meetings of the Academy of Aphasia, Chicago, 1963; Niagara Falls, 1964; 1965; Chicago, 1966.
  - 5. Present status
    - a. Growing appreciation on part of investigators of contributions that can be made by various disciplines.
      - a-1. We no longer expect one discipline to provide answers to all the significant questions that need to be asked about aphasia in adults, nor does one discipline expect to be able to deal with all of these.
      - a-2. We do not yet have sufficient information in any of the relevant areas to be able to formulate a unified theory of aphasia.
    - b. Clinicians, faced with the practical problem of treating patients, probably remain the most bewildered.
      - b-1. No discipline has advanced far enough to be able to provide a scientific basis for treatment of aphasia.
      - b-2. Various rationales for treatment have been proposed and approaches suggested, and some of these have been incorporated into treatment programs.
      - b-3. At present state of knowledge, an eclectic approach seems indicated. It is necessary to utilize the best information that is available from diverse sources.
- B. Neurological background of aphasia.
  - 1. Although the first interest of neurologists in aphasia was directed toward topological localization of cerebral functions, today neurologists and neurophysiologists are asking more sophisticated questions.
  - 2. Present questions are directed towards the nature of the brain mechanisms involved in the higher integrative processes required to produce complex behaviors, of which language is one.

    - a. Breakdown of language mechanisms with brain injury or disease may lead to some insights into the nature of the mechanisms involved.
  - 3. Studies of sensory processes in health and disease are related to kinds of impairment frequently observed in aphasia. These include:
    - a. Studies of perception, including alterations of perception following brain damage, involving discrimination, recognition, and recall of perceptual patterns.
    - b. Studies of feedback mechanisms.
    - c. Studies of interactions between sensory modalities.
    - d. Studies of interactions between hemispheres.
    - e. Studies of evoked sensory potentials.
      - e-1. May provide insights into the kinds of interferences that result from brain damage.
      - e-2. May make it possible to define stimulus parameters that facilitate responses in brain-injured subjects, thus providing information upon which clinical rationales may be based.
  - 4. Studies of neurochemical processes
    - a. Already being related, although not yet definitively, to problems of learning and memory.
  - 5. Neurological status of aphasic patients
    - a. It is impossible to understand either the general or the language behavior of the aphasic patient without consideration of his general neurological status.
    - b. An optimal regime for any aphasic patient must be based on optimal management of neurological problems.
- C. Psychological background of aphasia
  - 1. Psychologists generally regard language as a form of behavior.
    - a. Some psychologists, notably the Russian investigators like Vigotsky and Luria, have been interested in the role of language in thinking and in learning, and in the control of behavior.
    - b. Other psychologists have been interested in the alterations of behavior produced by brain injury or disease.
  - 2. Clinical psychologists have generally been interested in two problems:
    - a. Assessment and measurement of aphasic disabilities.
    - b. The impact of disability upon the individual, and in the ability of the individual to adjust to his altered situation.
  - 3. Experimental psychologists have chiefly been interested in the methods by which specific behaviors can be altered.
    - a. This interest has led some psychologists to consider the problem of retraining aphasic patients in the context of specific learning theories, such as operant conditioning.
      - a-1. It has not been established that conditioning theory constitutes an adequate explanation for complex behaviors, or that learning theory is relevant to recovery of function in aphasia.
      - a-2. In spite of theoretical inadequacies, it is possible that careful programming of steps of therapy may lead to some insights into the nature of the therapeutic process, when a disinterested evaluation of this work can be made.
  - 4. Neuropsychology
    - a. Has been defined as "the interdisciplinary study of psychological behavior related to brain dysfunction or pathology, or more generally, the relationship of central nervous system mechanisms and behavior." (International Neuropsychology Society, 1965)
    - b. Has become a major area of concern to many psychologists, as well as neurologists.
  - 5. Psycholinguistics
    - a. A comparatively new discipline that crosses the fields of psychology and linguistics.
    - b. Psycholinguists have probably contributed most to studies of language acquisition in children.
    - c. Have been a few studies of syntactical usage of aphasic patients.
- D. Linguistic background of aphasia
  - 1. Linguists are generally interested in what the breakdown of language processes in aphasia can tell us about the nature of language itself.
  - 2. There are many basic questions about language that are still unanswered. Some of the relevant questions that are being asked today include the following:
    - a. What accounts for the fact that all known human societies have evolved a language system that makes possible

communication of past as well as present events, and of remote as well as immediate contingencies?
b. What accounts for the fact that although non-human species develop complex and intricate communication systems, none has been known to evolve a language in the sense defined above, nor has it been possible to teach an animal a language?
c. What accounts for the universal features that apparently exist in all natural languages that have been studied?
d. What linguistic features does the brain utilize as it processes language?
e. What do children learn, as they acquire language, that makes it possible for them to generate sentences that they have never heard, at a very early age?
f. What is the order in which the various phonemic, morphological, and syntactical features of language are acquired?
g. What are the inter-relations between semantic and syntactical aspects of language?
h. What are the inter-relations between these aspects of language?
i. What is the relationship between semantic and syntactical aspects of language?
j. Are these aspects of language differentially impaired in aphasia? If so, under what conditions, and to what extent?
k. Has the aphasic patient lost language competence, in the sense that Chomsky uses this term, or has he merely incurred impairment of some of the performance aspects of language? In other words, has the aphasic patient lost the knowledge of his language that is common to all its users, or has he merely incurred impairment of some of the mechanisms involved, such as retrieval, short-term memory, span, feedback control, et cetera?

3. Present state of knowledge
a. It seems obvious that none of these questions have simple or easy answers.
b. It is also readily apparent that answers to questions like these, and many more, are directly relevant to aphasia.

II Basic Problems

A. Incidence of aphasia in adults
1. No reliable information is available.
2. *Report to President*, 1964, estimated that at least 2 million people now alive in U.S. have suffered a stroke.
a. In current Minneapolis study of Cerebrovascular Disease (Univ. of Minn.) 124 subjects with recent occlusive lesions have been studied. Of these subjects, 42 per cent showed aphasia upon examination.
a-1. Some may recover spontaneously.
b. No available information on aphasia resulting from other etiologies.
c. Conservative estimate: not less than a million adult aphasics in U.S. today.

B. Etiology of aphasia in adults is usually clear from history.
1. Cerebrovascular accident
a. Occlusion of cerebral vessel
a-1. Thrombotic
a-2. Embolic
b. Rupture of cerebral vessel
b-1. Weakness in wall of vessel (aneurysm)
b-2. High blood pressure
b-3. Traumatic rupture
2. Brain tumor
3. Head injury
4. Infectious processes
5. Toxic processes

C. Underlying pathology
1. Aphasia may result from any condition that alters conductivity of cerebral tissue.
a. Destruction of cell bodies or cell processes
b. Interruptions of fiber tracts
c. Alterations of brain chemistry
c-1. Within cell
c-2. At membrane
c-3. At synapse
c-4. These relationships are not yet clearly understood
2. Loci of lesions resulting in aphasia
a. General agreement that lesions resulting in persistent aphasia are usually in left cerebral hemisphere.
a-1. This finding is more consistent in right handed individuals than in left.
b. Persistent aphasia is more prevalent with temporo-parietal than with frontal lesions.
c. Severity of aphasia appears to be related to both locus and extent of lesion.
d. Specific symptoms appear to be related chiefly to locus of lesion.
d-1. This is what makes differential diagnosis possible.

d-2. Localization is possible in terms of broad systems involved, although not in terms of discrete cortical areas.
3. Genetic bases of pathology
a. Congential weaknesses or malformation of cerebral vessels
b. Possible genetic factor contributing to tendency toward cerebral disease
D. General symptoms of aphasia in adults
1. Absence of function or total dysfunction seldom or never observed.
a. Some residual language functions almost always preserved.
a-1. Sometimes, under some circumstances, patients respond appropriately to spoken language.
a-2. Sometimes, under some circumstances, some kinds of utterances occur.
2. Isolated pure disorders seldom or never observed.
a. Have been reported by no investigator who reported objective test findings over a series of aphasic subjects.
a-1. Head, 1926, 26 subjects
a-2. Weisenburg and McBride, 1935, 60 subjects
a-3. Wepman, 1951, 68 subjects
a-4. Schuell, Jenkins, Jimenez, 1964, 158 subjects
E. Limitation of ability to process, pattern, and retain auditory stimuli
1. Comparatively little is known about disorders of central auditory processes.
a. Unilateral cerebral lesions have no demonstrable effect on threshold of either ear (Jerger 1964).
b. No evidence that bilateral cerebral lesions usually affect auditory threshold.
c. Reducing redundancy of verbal messages by low-pass filtering, acceleration of rate, periodic interruption, and variation in message rate resulted in impaired perception in contralateral ear in patients with temporal lobe tumor (Bocca 1955, 1958, 1963).
d. Binaural interaction effects, particularly of competing messages, also resulted in impaired perception in subjects with cerebral lesions (Bocca 1955, 1963; Kimura 1961 a, b).
e. Effects of reduced redundancy and competing messages occur with lesions of either cerebral hemisphere.
e-1. It follows that phenomena underlying these effects cannot account for aphasic difficulties understanding spoken language, since they are observed when no aphasia is present.
f. Hirsch (1962) and Jerger (1964) have emphasized that although tests involving verbal materials appear most sensitive to central auditory damage, these techniques do not permit analytic description of the fundamental properties of the central auditory system.
2. Dimensions of auditory impairment studied in aphasia
a. Impaired phoneme discrimination (Luria, 1966; Schuell, 1965).
b. Impaired word recognition (Schuell and Jenkins, 1961 a; Schuell, Landis, and Jenkins, 1961 b).
c. Impaired auditory retention span (Schuell, 1965).
d. Above defects show some evidence of hierarchial order in aphasia.
d-1. Some impairment of word recognition results from impaired phoneme discrimination, but not vice versa.
d-2. Some impairment of word recognition is obviously not related to impaired phoneme discrimination, as when aphasic patients confuse words like chair and table, boy and girl, or cat and dog.
d-3. When word recognition is disturbed, auditory retention span tends to be reduced, although the converse is not necessarily true.
3. Hypotheses concerning fundamental nature of auditory impairment in aphasia.
a. Distortions of input resulting from noise in the system.
b. Distortions of input produced by defective timing or sequencing of input signals.
c. Reduction of information resulting from defective scanning or sampling of input signals.
d. Reduction of information resulting from defective matching of incoming signals with previously-stored patterns.
e. Reduction of information as result of defective ability to retain auditory input long enough for processing.

        - f. Reduction of information as a result of weak or inadequate transmission of input signals.
    - 4. Pavlovian concept of acoustic analyzers (Luria, 1966).
        - a. Sensation is regarded as an active reflex process associated with selection of the essential (signal) components of the stimuli, and inhibition of non-essential components.
        - b. Process includes effector mechanisms for tuning the peripheral selector apparatus.
        - c. The reflex theory incorporates process of analysis and synthesis of signals in first stage of arrival.
            - c-1. Luria considers that this analytic-synthetic function is what is disturbed in aphasia.
        - d. Strength of theory
            - d-1. Attractiveness lies in recognition of dynamic and integrative properties of perception.
            - d-2. Compatibility with modern neurophysiological theory, which holds that complex selective and integrative processes occur at all levels of the nervous system.
        - e. Weakness of theory
            - e-1. Fails to specify mechanisms of analysis and synthesis, or to define these processes precisely in relation to auditory perception.
- F. Limitations of ability to process, pattern, and retain visual stimuli
    - 1. Central visual processes
        - a. Visual acuity not usually affected by cerebral lesions.
            - a-1. Exception is when the optic nerve itself is involved, as in some head injuries, or with some tumors.
        - b. Most common sequela of unilateral cerebral lesions is a homonymous field defect.
            - b-1. Results from interruptions of optic radiations between the lateral geniculate body and the cortex.
            - b-2. Reduces visual fields in corresponding sectors of each eye.
        - c. Cortical blindness.
            - c-1. Considered to result from destruction of extrinsic visual cortex.
            - c-2. Definitive clinical studies are lacking, so that this condition cannot be described with precision. It is probable that a variety of clinical syndromes have been included under this label.
        - d. Alterations in visual perception following circumscribed lesions in the visual cortex (Bender and Teuber, 1949).
            - d-1. Based on extensive clinical studies of 68 naval casualties of WW II.
            - d-2. Most frequent alteration was increased fluctuation of visual thresholds.
            - d-3. Double simultaneous stimulation demonstrated obscuration or extinction, of a stimulus in a visual field which appeared intact on ordinary perimetry.
            - d-4. Subjects required more time for perception of visual contours.
            - d-5. Visual contours lacked stability. Impairment included rotations, alterations of size, and deformations of contours. These signs sometimes appeared only in one quadrant or one half of the visual field.
            - d-6. Spatial organization was altered. Objects appeared distorted, too large or too small, too near or too far.
            - d-7. Perception of movement was altered. Moving objects were sometimes reported as a series of stationary objects.
            - d-8. Suggested mechanism: an abnormal intermittance of cerebral activities subserving vision.
        - e. Extrinsic and intrinsic visual systems (Pribram, 1958).
            - e-1. Extrinsic visual system consists of lateral geniculate nuclei in thalamus, the occipital regions to which the optic radiations project (extrinsic visual cortex, Brodmann Area 17), and cortico-thalamic and thalamo-cortical relays between these areas. This system receives its primary sensory input from the optic nerve.
            - e-2. The intrinsic visual system consists of non-specific nuclei in the thalamus, of cortical areas which receive input from the intrinsic visual system (the intrinsic visual cortex, Brodmann Areas 18, 19), and of cortico-thalamic and thalamo-cortical relays between these areas.

- e-3. Ablation experiments with monkeys led Pribram to conclude that damage to the extrinsic visual system resulted in severe impairment of visual discrimination, with only gross discriminations retained.
- e-4. Damage to the intrinsic visual system also resulted in impaired visual discrimination, but the impairment was less severe.
- e-5. Pribram concluded that the extrinsic and intrinsic visual systems were inter-dependent, and functioned together as a hierarchical system.

f. Visual analyzers (Luria, 1966).
  - f-1. Visual analyzers considered to subserve discrimination of "signal" signs (essential to organism) and rejection of unessential signs.
  - f-2. Visual processes are both afferent and efferent (transmission of impulses bidirectional rather than unidirectional).
  - f-3. Damage results in disturbance of selectivity. Grosser discriminations may be retained while finer ones are lost.
  - f-4. Probable mechanisms: rapid fatigue from visual reception, impaired visual adaptation, raising of visual thresholds, et cetera.

2. Visuospatial processes
  - a. Factor analysis of test results obtained from 157 aphasic subjects showed a clear-cut visuospatial factor (Schuell, Jenkins, and Carroll, 1961).
    - a-1. This factor included all the matching, copying, drawing, and object assembly tests on the battery.
  - b. Tasks represented on the visuospatial factor all required somatosensory as well as visual information.
    - b-1. The visuospatial factor correlated most highly with the factor representing speech movements ($r=.58$) which also required kinesthetic and tactile information.
    - b-2. The second highest correlation ($r=.55$) was with the visual factor.
  - c. Rationale
    - c-1. Spatial concepts derive from movements in space (movements of the eyes, the head, postural movements, movements used in manipulating objects, and in approach and avoidance) as well as from visual information.
    - c-2. These movements result in a continuous flow of feedback information, which permits us to move around freely in space, to avoid obstacles, to turn left or right appropriately, to control extent of movement, to manipulate objects in space (such as cars and tennis balls), and to perform many kinds of skilled acts.
    - c-3. We perceive objects visually, but judge their relationships in space in relation to ourselves.
  - d. Visuospatial perception is often disturbed with parietal lesions (Critchley, 1951).

3. Aphasic disturbances of visual and spatial perception.
  - a. Most adult aphasics tend to utilize information less adequately than nonaphasics.
    - a-1. Occasionally misreads words, suggesting neglect of fine visual cues (Schuell and Jenkins, 1961 a).
    - a-2. Retention of visual patterns may be below that of nonaphasics, reflecting neglect of visual details.
    - a-3. Recall of learned visual patterns may also be somewhat less dependable. Errors include occasional reversals of letter forms, and omissions of silent letters in words.
    - a-4. In most aphasic patients such errors tend to decrease and disappear as reading and writing skills increase.
  - b. Partial visual imperception (Penfield and Roberts, 1959).
    - b-1. More serious and persisting disruption of visual processes is observed in some aphasic patients.
    - b-2. Consistent impairment of visual discrimination is demonstrated on tasks such at matching geometric forms, matching pictures, match-letters, and matching words.
    - b-3. With severe visual impairment, performance is reduced on gross tasks, such as matching simple patterns, although enough performance is usually possible to

enable the examiner to explore the limits of the disability.

- b-4. Patients who perform on any visual tasks can usually match colors. Subtle color discriminations may be reduced, but this cannot usually be ascertained reliably, since variability among nonaphasics is so great.
- b-5. With milder impairment of visual processes, only finer visual discriminations are reduced. This loss adds another dimension of impairment to the reading ability of some aphasic patients.
- b-6. These patients tend to persistently confuse letters with similar visual configurations.
- b-7. Word recognition is abnormally slow. Some patients initially have to decipher each letter individually and spell the word before recognition occurs. They can sometimes be observed to trace a letter on the page or in the air, using proprioceptive cues to supplement reduced visual information.
- b-8. Patients tend to decipher the beginning of the word and guess at the end of it.
- b-9. Recall of learned visual patterns (both letters and words) is lost or defective. Some patients have to relearn each visual symbol, upper case, lower case, print and script, before writing is possible.
- b-10. Letter forms may be reversed both horizontally and vertically, distorted, or confused with other forms with similar visual patterns.
- b-11. Patients tend to spell phonetically, and have great difficulty recalling double letters and silent letters.
- b-12. The same kinds of errors appear on both reading and writing.
- b-13. When spatial impairment is also present, confusion of directionality is observable on copying, drawing, and writing. The patient frequently does not know where to start a letter, in which direction to proceed, or how to join two letters in a word. With gross impairment he may for example draw the spokes in a wheel in a horizontal or a vertical plane.
- b-14. With severe spatial imperception the patient may ignore one side of the figure, drawing a man, for example, with only one arm or one leg. Pressed to add a missing limb he may draw it detached from the figure, or attached in some grotesque fashion.
- b-15. In solving arithmetical problems, the patient with spatial impairment becomes confused because he does not know where or how to write down partial arrays so that he can deal with them.
- b-16. When blurring or obfuscation of vision is present, the patient tends to have difficulty following the line and keeping his place in reading, and frequently omits words as he scans a line.
- b-17. Aphasic patients readily accommodate to hemianopic field defects, unless spatial perception is also impaired.

G. Limitations of comprehension of discerned sensory patterns.

1. Limitations of comprehension of discerned sensory patterns in adult aphasia are arbitrarily considered to imply the following conditions:
    - a. No distortion of incoming stimuli by interference or noise.
    - b. No reduction of incoming stimuli by intermittance or weakness of transmission.
    - c. Discussion will be limited to consideration of comprehension of meaningful units of language.
    - d. "Meaning" is used in the sense defined by Carroll (1964): "A 'meaning' can be thought of as a standard of communicative meaning that is shared by those who speak a language."
2. Although the definition, "discerned sensory patterns" excludes perceptual disturbances as a contributing factor to impairment of comprehension, the distinction may not be valid for aphasic adults.
    - a. It has not been conclusively demonstrated that subtle alterations of auditory perception can be ruled out completely in aphasia.
    - b. It has not been conclusively demonstrated that perception and comprehension can be completely separated. Modern perceptual theory, in fact, suggests considerable interdependence of

these processes (Hayek, 1952; Hebb, 1949; Brain, 1961).

3. Evidence of adult aphasia none the less suggests that some limitations of language comprehension are independent of perceptual alterations. This evidence is as follows:
   a. There is a frequently reported and well-documented tendency for adult aphasics to confuse words associated in meaning, such as chair-table; door-window; man-woman; et cetera.
   b. There is a well-documented tendency for such errors to occur in all language modalities: on naming objects or pictures; on pointing to objects or pictures named by the examiner; on matching printed words to pictures; on writing words to dictation; in spontaneous speech, and in spontaneous writing. These errors will be labelled *semantic errors.*
   c. *Perceptual errors,* consisting of confusions between words that sound alike or look alike, and semantic errors are frequently found in the protocols of the same patients.
      c.-1. As recovery progresses, the percentage of perceptual errors tends to decrease while the percentage of semantic errors increases.
      c-2. Semantic errors are considered the "best" errors, since they predominate in the records of patients who make the fewest total errors on vocabulary tests (Schuell and Jenkins, 1961 a).
4. Impaired comprehension of words (vocabulary items or lexis) in adult aphasia.
   a. The most common impairment of comprehension of words in aphasia is confusion of referential meaning (*semantic errors*).
      a-1. This class of errors has no obvious sensory component.
      a-2. This class of errors appears to follow linguistic rather than sensory rules.
   b. Regularities of observed errors of lexis.
      b-1. Semantic errors resemble the popular responses of normal subjects on word association tests (Schuell, 1951).
      b-2. The most common confusions are between words most closely associated in lexical categories such as names of colors, days of the week, numbers, opposites (black-white, north-south, yes-no, et cetera).
      b-3. In general, aphasic patients comprehend common words better than words that occur less frequently in general language usage (Schuell, Jenkins, and Landis, 1961 b).
      b-4. In addition, what Roger Brown (1958) has called a utility principle appears to operate: patients tend to comprehend words with strong personal significance better than words that are unrelated to areas of individual interest. Thus a lawyer may respond better to words selected from a legal vocabulary than to words that occur more frequently in general language usage.
      b-5. The same linguistic principles operate in comprehension of written language.
5. Impairment of comprehension resulting from reduction of verbal retention span.
   a. Comprehension errors increase in aphasia as the length of the stimulus is increased (Schuell, Jenkins, and Jiménez-Pabón, 1964; Schuell, 1965).
      a-1. The patient may be able to point to items in a picture named in series of two, but not in series of three; or in series of three, but not in series of four or five.
      a-2. He may be able to follow short directions, but not two or three of the same directions combined.
      a-3. Brown and Bellugi (1964) consider that in repetitions of young children, the constraint of length or span is a limitation on the length of message the children are able to program or plan, rather than a constraint of immediate memory.
   b. Constraint of immediate memory versus length of message that can be programmed in adult aphasia.
      b-1. The relationship between the length of message that can be comprehended and the length of message that can be programmed is indicated by selected test correlations derived from analysis of scores obtained from 157 aphasic patients on the Minnesota Test

for Differential Diagnosis of Aphasia (Schuell, Jenkins, and Carroll, 1961):

Correlations Between Identifying Objects Named Serially[*] *and Other Selected Tests*

Following directions of progessive length (auditory comprehension)	.95
[**]Repeating digit series of progressive length (auditory retention span)	.81
[**]Repeating sentences of progressive length (auditory retention span)	.78
Picture description (connected speech)	.77
Generating sentences in writing	.82

b-2. Correlations tell us nothing of the nature of the relationships involved.

b-3. It would appear to be premature to rule out the number of units that can be retained in short term memory for processing as a constraint upon language, particularly as the mechanism that is involved does not appear to be modality specific. This does not imply that other constraints may not operate at the same time.

H. Limitation of ability to formulate meaningful verbal material.

1. Limitations of lexis.
   - a. Aphasic patients appear to experience difficulty in retrieving words from the permanent memory store.
   - b. That vocabulary items in the permanent memory store are not lost is demonstrated by the following generally accepted observations:
     - b-1. Emergence of appropriate words under conditions of emotion or stress.
     - b-2. The ease with which words can be evoked by well-established semantic associations.
     - b-3. Paraphasic responses, in which the patient, unable to produce the word he wants to say, produces related words, such as these responses to *table*: chair; eat; supper; legs; coffee.
     - b-4. The emergence, with increasing frequency, of unpracticed vocabulary items, during the course of therapy.
   - c. Regularities observed in impaired retrieval of lexical items.
     - c-1. There is a correlation between ease of retrieval and frequency with which words are used in language.
     - c-2. The most common error is confusion between words related in meaning (semantic confusions). Suggests that this is one kind of cataloguing or indexing that the brain does.
     - c-3. Same kinds of errors occur in nonaphasics as "slips of the tongue."
     - c-4. Frequency of errors decreases gradually throughout recovery period.
   - d. Phonemic errors
     - d-1. A class of inconsistent phonemic errors appears to reflect impaired recall of learned auditory patterns.
     - d-2. A more consistent class of errors appears to reflect phonemic disintegration stemming from reduced sensorimotor, as well as from reduced auditory feedback control. Confusion between phonemes with similar articulatory features has been reported (Schuell, Jenkins, Jiménez-Pabón, 1964), which supports the hypothesis of reduced sensorimotor feedback.
     - d-3. A third more heterogeneous class of errors, reflects various kinds of dysarthria. Variability between patients reflects various amounts of involvement of various segments of the articulatory apparatus, or sometimes, merely loss of precise movements and firm contacts.
2. Limitations of syntax
   - a. In the early period of recovery patients with severe aphasia tend to use a preponderance of single-word utterances.
   - b. Commonly used phrases tend to appear early in the course of recovery.
   - c. Other early utterances appear to be of the topic-comment type, such as, "Me — go home."
   - d. Some syntactical rules tend to operate as soon as adult aphasics combine words at all.

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[*] Used as test of auditory span for patients who cannot repeat.

[**] Correlation between these two tests is .98.

e. As connected speech emerges, some syntactical discriminations, such as distinctions between singular and plural forms, gender of pronouns, et cetera, tend to be neglected.
f. Syntactical discriminations that are neglected in situations where the aphasic patient is struggling to communicate, frequently appear in more relaxed utterances.
g. Syntactical discriminations neglected at one stage of recovery, are made spontaneously, as language increases.
h. There probably is some hierarchy in the order of recovery of syntactical rules. One might postulate that there might be a correlation between this order and frequency occurrence of structures embodying these rules in general language usage. This has not been documented either for aphasic or nonaphasic users of language.
i. Aphasic adults who speak in sentences appear to use "kernel" sentences, questions, and negative transformations with equal ease. Passive transformations seem to occur less frequently, but this is probably also true of the utterances of nonaphasics.
j. There is probably a relationship between length of utterance and syntactical structures used in adult aphasia. This has not been documented.

3. Competence versus performance factors in adult aphasia.
    a. Competence is defined as the speaker-hearer's knowledge of his language (Chomsky, 1965).
        a-1. Competence is unaffected by grammatically irrelevant conditions such as memory limitations, shifts of attention and interest, and by random or characteristic errors made by the speaker in applying his knowledge of the language in actual performance.
        a-2. In adult aphasia competence factors appear less affected than performance factors, as evidenced by the aphasic's spontaneous application of the rules of his language as his available vocabulary increases, and his utterances increase in length and fluency.
        a-3. Longitudinal studies are needed of the utterances of severe aphasics during the period of transition from chiefly one-word utterances to the emergence of grammatical sentences. The studies need to go beyond distributions of word frequency and word classes to include syntactical operations and consideration of underlying base structures.
        a-4. Relevant questions include the following:
            What are the rules the aphasic patient operates with when combinations of words begin to occur in his utterances?
            Are these rules similar to the rules used by young children during a comparable stage of language acquisition (Brown and Bellugi, 1964; McNeil, 1966; Fodor, 1966; Slobin, 1966)?
            Are there systematic changes in the rules used by adult aphasics over time: does Grammar T^1 differ from Grammar T^2, and Grammar T^2 from Grammar T^3 in an orderly way?
            Do adult aphasics make more morphological than syntactical errors (Slobin, 1966)?
            What is the nature of the constraints upon the early utterances of aphasic patients?
            Are the underlying base structures of language intact in the adult aphasic?
            What is the role of practice in retraining (McNeil, 1966)?
    b. Performance is defined as the actual use of language in concrete situations.
        b-1. Conditions that might presumably alter the language performance of aphasic subjects include impairment of the speech musculature; impaired auditory discrimination; impaired feedback control (including both auditory and somatosensory); impaired auditory discrimination; impaired recall of learned auditory patterns; impaired ability to retrieve vocabulary items from the lexis, and reduction of short-term memory.
        b-2. Brown and Bellugi (1966) have postulated that constraints upon the length of children's utterances are restrictions on the

length of unit that can be programmed rather than restrictions of short-term memory. McNeil (1966) has suggested that more than one kind of short-term memory may play a role in linguistic performance: one for phonological production, one for grammatical comprehension, and one for grammatical production. These suggestions obviously require investigation in relation to aphasia in adults, as well as in relation to language acquisition.

c. Questions regarding both competence and performance factors in adult aphasia must be answered through future research.

c-1. No rationale for therapy is possible until more information about language processes is available. Relevant questions are the following:
Should we try to teach the adult aphasic the rules of his language?
Instead of this, shall we try to lead him to develop rules, perhaps by expansion of his utterances (Brown and Bellugi, 1964; McNeil, 1966)?

Instead of either of these, should we concentrate on performance factors, using techniques for facilitation of movement patterns, stimulation of auditory discrimination, retrieval of lexical items, and increase of verbal retention span?

I. Limitations of ability of spontaneous expression

1. Voluntary and involuntary processes

a. Hughlings Jackson (1915) pointed out that nowhere in the body is there sharp demarcation between voluntary and involuntary processes, although with disease of the hemispheres there is a tendency for the more voluntary processes to be affected, while the more involuntary processes are preserved.

b. In general voluntary processes are learned patterns, and include all skilled movements.

b-1. It is possible for highly overlearned movement patterns to attain a degree of automaticity, and thus require less voluntary control than less highly-organized patterns.

b-2. Voluntary control implies feedback mechanisms.

c. Voluntary and involuntary speech.

c-1. Hughlings Jackson (1958) also pointed out that in aphasia there is preservation of some of more involuntary and automatic forms of language, with loss of more voluntary forms.

c-2. Among the more involuntary and automatic forms Jackson included recurring automatisms, emotional utterances, and highly-overlearned language sequences, such as counting. To Jackson's categories Weisenburg and McBride (1935) added reactive responses determined by extraneous stimuli that need not elicit an emotional response.

c-3. It is probable that Jackson's principle accounts for some of the phenomena of aphasia, such as the recurring or occasional utterances observed with severe aphasia. It is not adequate, however, to explain all limitations of ability of spontaneous expression.

2. Responsiveness to environment.

a. Responsiveness to environment may be altered by reduction of incoming stimuli, as with some kinds of thalamic involvement.

a-1. In such cases a patient with considerable residual language may rarely speak, even when he is addressed directly.

a-2. To a strong meaningful stimulus, however, he may respond with appropriate utterances of considerable complexity, as long as his attention is engaged. These utterances do not resemble the occasional utterances described by Jackson which are usually short and unsustained.

a-3. The differentiating criterion is the discrepancy between the difficulty of eliciting responses, and the well-organized responses that are sometimes obtained.

3. Severity of aphasia.
   a. With severe aphasia limitations of ability of spontaneous expression are probably multiply determined.
      a-1. Inability to retrieve items from the vocabulary store is probably the largest contributing factor.
      a-2. Severe dysarthria may contribute to loss of spontaneity of speech, since there is almost always loss of automaticity on the phonological level. It may require so much effort to produce intelligible speech that the patient tends to avoid talking.
      a-3. The phonemic disintegration that results from severe sensorimotor involvement may produce similar results. However, most patients with sensorimotor involvement tend to reduce length rather than frequency of utterances. It is unlikely that this factor accounts for the syntactical features of such utterances, however.

J. Limitations of ability to imitate linguistic patterns
1. Auditory impairment.
   a. With impaired auditory perception imitation of linguistic patterns is defective because patterns are imperfectly differentiated.
      a-1. With impaired auditory perception patients frequently know that what they have heard or said does not sound just right. They frequently ask to have the stimulus repeated, or make successive attempts to correct errors. However, at other times the patient may not know if his response was correct when it was.
   b. Impaired auditory perception may or may not be complicated by disruption of feedback mechanisms (Chase, Sutton, and Rapin, 1961; Chase and Guilfoyle, 1962).
      b-1. When feedback mechanisms are disrupted the patient has difficulty recognizing his errors, even when he has produced jargon.
   c. Impaired auditory retention span.
      c-1. The patient is able to repeat short patterns but not longer ones. Restrictions of length apply to word length in terms of syllables, as well as to series of digits, phrases, and sentences.
   d. In general more success is obtained with meaningful than with nonmeaningful language units.
2. Sensimotor impairment.
   a. In sensorimotor impairment, imitation of speech patterns is defective because of loss of information concerning position of articulators, and direction and extent of movements.
      a-1. The patient frequently behaves as though he did not know where his tongue was in his mouth, or what to do to make it move in a given direction or to a given position.
   b. The usual effect is distortion, omission, or substitution of phonemes.
      b-1. Occasionally impairment is so severe that no imitation of linguistic patterns is possible initially.
      b-2. The most persisting errors are confusions between phonemes with similar articulatory patterns such as p-b-m, t-d-n-l, f-v, k-g, et cetera.
      b-3. Research is needed to investigate the relationship between sensorimotor impairment in aphasia and distinctive phonemic features (Jakobson, Fant, and Halle, 1963).
3. Reduction of both auditory and somatosensory information.
   a. Impairment of both systems is probably more common than impairment of either in isolation in adult aphasia.
      a-1. In some patients the principle factor seems to be reduction of auditory information; in others loss of somatosensory information appears to predominate.
   b. Auditory processes seem to be higher in the hierarchy of control of speech production than somatosensory processes (Fant, 1960), since intensive auditory stimulation with meaningful linguistic patterns produces better results than working with movement patterns per se (Schuell, Jenkins, and Jiménez-Pabón, 1964).
4. Dysarthria.
   a. Dysarthria results from paralysis or weakness of some of the speech musculature, or from loss of control of higher over lower motor centers.

a-1. Various kinds of dysarthria may occur as a result of cerebral injury or disease, depending upon the part of the speech musculature affected (larynx, tongue, palate), or the systems involved (extrapyramidal or cerebellar systems, for example).

b. Dysarthria may occur in the presence or absence of aphasia.

b-1. Bay (1962) and others have pointed out the necessity for discriminating between dysarthria and aphasia. Dysarthria does not imply any reduction of language.

b-2. When dysarthria and aphasia coexist there is no correlation between the severity of aphasia and severity of dysarthria. Dysarthria may be severe and aphasia mild, vice-versa, or both may be mild, or both severe. This is not true of sensorimotor involvement, which tends to correlate with severity of aphasia, as well as with other indices of severity of neurological involvement (Schuell, Jenkins, and Jiménez-Pabón, 1964).

b-3. In dysarthria, as opposed to sensorimotor involvement, phonemic discrimination is usually well-preserved.

b-4. Dysarthric patients, unlike patients with sensorimotor involvement, require direct motor practice.

c. The effect of dysarthria is usually to reduce the accuracy and fluency of speech production.

c-1. Imitation of language patterns is usually possible but defective.

III. Treatment of Aphasia in Adults

A. Prevention.

1. Since aphasia is only a symptom of cerebral injury or disease, prevention must be directed towards elimination of cerebral disease and optimal control of conditions conducive to cerebral injury.

a. Control of cerebral disease is a medical problem.

2. Prevention of cerebrovascular disease.

a. Prevention of strokes is one aspect of the National Program for Prevention of Heart Disease, Cancer, and Stroke.

b. Directions of approach.

b-1. Epidemiological studies to identify factors that influence incidence.

b-2. Studies of subjects in stroke and control groups to identify factors that contribute to cerebral disease.

b-3. Search for new drugs for control of viral infections, hypertension, and arteriosclerosis.

b-4. Perfection of surgical procedures for removal of emboli, thromboses, and repair of damaged walls of vessels.

3. Head injuries.

a. Probably cannot be eliminated.

a-1. Incidence increases in time of war.

a-2. Incidence of head injuries from highways accidents appears to be increasing as a result of ground travel at increasingly high speeds. Control of safety of vehicles can presumably reduce incidence of accidents resulting in head injuries.

B. Mitigation of aphasia.

1. Effects of aphasia can be mitigated by treatment and family counseling directed towards optimal management of patient.

2. Results of treatment.

a. Results of treatment are related to the locus and extent of brain damage incurred, and the condition of the remainder of the brain.

b. Extent of recovery can be reliably predicted if patients are examined when neurologically stable. Thus realistic therapeutic goals can be established (Schuell, Jenkins, and Jiménez-Pabón, 1964).

3. Goals of treatment.

a. A few aphasic patients return to occupations that place high demands on linguistic skills.

b. Others return to occupations with some adjustment of duties.

c. Many aphasic patients find employment that places little demand upon language.

d. Some aphasic patients are employable only under sheltered conditions.

e. Many aphasic patients were retired, or are forced into retirement by persisting limitations. Treatment is desirable for these patients to insure that they remain communicating individuals, able to participate in family and community life, and maintain maximal independence and functional integrity.

f. With scattered or generalized brain damage, patients are often incapable of persistent effort required for maximal recovery of functions. Limited goals, such as improvement of comprehension, increase of available language, or increased intelligibility can sometimes be achieved however, which serves to reduce frustration, and thus contribute to the welfare of the patient and his family.

g. Some aphasic patients, with massive lesions will never acquire functional speech. Short-term therapy is desirable (1) to improve comprehension, (2) to demonstrate to the patient and his family that he is not mentally deficient, (3) to help the patient and family achieve a favorable milieu, and (4) to to prevent withdrawal and depression.

4. Evaluation of treatment.

a. Some studies to assess the effects of treatment have been attempted (Vignolo, 1964).

b. Such studies present enormous methodological difficulties.

b-1. Matching experimental and control subjects on relevant variables is virtually impossible.

b-2. Controlling variables that affect the performance of untreated subjects is virtually impossible.

b-3. Reliable and adequate measures of improvement are difficult to achieve because of variability in kind and degree of impairment that exist in aphasic populations.

b-4. Differences between therapists and methods of treatment may be very large.

c. Alternative procedures.

c-1. At the present stage of knowledge it would appear more heuristic to explore treatment variables that can be controlled, to determine the principles upon which sound rationales for treatment can be based, and the conditions under which they operate.

C. Rehabilitation.

1. The neurophysiological basis of the recovery process in adult aphasia is not known.

a. The theory that the undamaged hemisphere takes over language functions in adult aphasics is probably not tenable (Penfield and Rasmussen, 1950; Lennenberg, 1962).

a-1. Lennenberg (1962) observes that the earlier a lesion in the left hemisphere occurs the less grave is the outlook for language. He concludes that language learning in the right hemisphere can take place only between the ages of two to about thirteen.

b. The consensus seems to be that linguistic information is redundantly coded and stored, probably throughout the whole brain, while the mechanisms for processing are organized in the right hemisphere in most adults.

b-1. If this view is correct, the process of recovery would appear to be chiefly that of forming new neural connections to permit more effective access and processing of linguistic events.

2. Rationales of treatment.

a. Rationales based on neurophysiological principles.

a-1. The specific neurophysiology of language is unknown, therefore there can be no sound neurophysiological rationale for treatment of aphasia today. However, although precise mechanisms are unknown, general principles of neurophysiological function can be inferred from a growing literature of neurophysiological and neuropsychological studies, which can be clinically tested with aphasic subjects.

a-2. Rationales based on neurophysiological principles generally employ methods of stimulation and facilitation.

a-3. The basic approach is that of manipulating stimulus dimensions to secure maximal responses, employing the principle of the adequate stimulus. It recognizes that stimuli to which a normal brain can respond may be inadequate in the case of an injured brain. Stimulus dimensions that can be manipulated include loudness, duration, intervals between presentations, number of successive presentations, choice of stimulus modalities, length of stimulus, pattern complexity, et cetera.

- a-4. A second principle is that of eliciting responses in order to utilize sensory feedback.
- a-5. Stimulation methods stress altering responses through successive stimulations rather than through instruction and correction. The assumption is that the patient responds as well as he is able to at each stage of recovery.
- a-6. A third principle is that of manipulating responses to increase facilitation.
- a-7. Controlled studies of the effects of systematically varied stimulus dimensions should be conducted.

3. Rationales based on learning theories.
   - a. Rationales based on various forms of learning theory generally utilize principles of conditioning and reinforcement.
     - a-1. Whether conditioning principles apply to complex behaviors, and particularly whether they apply to language must be considered open to question by reason of the growing body of studies in this area of generative linguistics (Chomsky, 1965; Brown and Bellugi, 1964; McNeil, 1966; Fodor, 1966, etc.).
     - a-2. Neither conditioning nor association theories can explain how the child learns to generate sentences he has never heard, why he abandons an over-practiced and over-generalized form in favor of a newly acquired one, and other similar phenomena that occur in the process of language acquisition.
     - a-3. Rationales based on learning theory generally assume that the aphasic patient has to be taught sounds, words, and syntactical structures, which is questionable in view of the fact that aphasic patients consistently produce utterances that have not been practiced.
   - b. Programmed learning.
     - b-1. Disadvantages.
       - (1) It is questionable that the rationale of operant conditioning is applicable to recovery of language in aphasia.
       - (2) Not enough programmes have been developed, and existing ones are unequal in quality.
       - (3) Programmes tend to be restrictive.
     - b-2. Advantages.
       - (1) Well-constructed programmes may provide stimulation for the aphasic patient, and opportunities for independent practice (sometimes this is not permitted, which seems unfortunate).
       - (2) Careful programming of therapy may stimulate the clinician to examine the therapeutic process more closely, and to become more aware of her own behavior and the reactions elicited in the patient.
     - b-3. The use of programmed materials in itself would seem to hold great possibilities, with critical and creative utilization of instrumentation and materials.
   - c. Linguistic rationales of treatment.
     - c-1. All rationales of treatment and aphasia make use of materials, programmes, and techniques that employ units of language.
     - c-2. A large problem is lack of knowledge of linguistic principles relevant either to the acquisition of language in children or the recovery of language in aphasia.
     - c-3. The current linguistic revolution is making it apparent that many generally accepted notions need to be examined. Efforts are being made to write grammars defining the linguistic competency of children at stages of language acquisition. Comparable studies of the recovery processes of aphasic patients with various patterns of language involvement are needed.
4. Essentials of treatment.
   - a. Complete information concerning the neurological status of the patient.

- a-1. The clinician needs to be aware of the patient's neurophysiological limitations.
- a-2. The clinician needs to be aware of ongoing medical conditions that may affect his performance from day to day, or the course of his performance over time.

b. Social history.
- b-1. It is important to know the patient's background, his past achievements and interests, and his present concerns.
- b-2. The clinician should be aware of the sources of satisfaction and dissatisfaction in the patient's present milieu.

c. Careful differential diagnosis.
- c-1. The clinician must know which cerebral processes are impaired and which are intact.
- c-2. The clinician must know the level at which performance breaks down in each language modality.
- c-3. The clinician must know the reason that performance breaks down when it does.

d. A program of therapy adjusted to the needs of the individual patient at a specific point in time.

5. Essentials of good patient management.
   - a. Family counselling.
   - b. Attention to the patient's adjustment to his situation.
   - c. An optimal medical milieu.
   - d. An adequate rehabilitation program.
   - e. A supportive social milieu.
   - f. A consistent treatment regime.

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C. *An Analysis of Symptomatology in Aphasia.* A third point of view, also different from—but not necessarily at variance with—either of the previous two presentations represents the philosophy of Dr. Joseph M. Wepman, whose text *Recovery from Aphasia,* New York: Ronald Press, 1951, was one of the early attempts in recent times to delineate the clinical problems and offer a logical scheme for management.

An intriguing idea offered by Wepman and his associates[1] has to do with an association between language development and aphasia. "The five stages of language development have a surprising relationship to the five types of aphasic disturbances we have been able to identify in our studies of adult impairment."

STAGE	TYPE OF APHASIA	STAGE OF DEVELOPMENT
1	Global	Pre-language; characterized by speechlessness.
2	Jargon	Pre-language; characterized by meaningless autistic and echolalic phoneme use.
3	Pragmatic	Progressive acquisition of comprehension. Oral expression of words and neologisms largely unrelated to meaning or below level of comprehension.
4	Semantic	The beginning use of substantive language progressing through nominal, verbal, and adjectival words. Characterized by one- or two-word groupings as complete expressions.
5	Syntactic	The use of syntax or grammar in oral expression.

In extension of much previous thinking about all these problems under discussion, Dr. Wepman has offered some fresh ideas that are pertinent in this setting. The following is his statement.

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[1] See Wepman, J. M., Jones, L. V., Bock, R. D., and vanPelt, D., "Studies in Aphasia: Background and Theoretical Formulations," *Journal of Speech and Hearing Disorders, 25* (1960) 323-332. Also, Wepman, J. M., and Jones, L. V., Five Aphasias: A Commentary on Aphasia as a Regressive Linguistic Phenomenon. *Research Publications Association of Nervous and Mental Diseases, 42* (1964), 190-203.

APPROACHES TO THE ANALYSIS OF APHASIA

by JOSEPH M. WEPMAN, Ph. D.

It is possible within a number of different schema to describe the deviations in language comprehension and use (i.e., aphasia in the classical sensory-motor classification such as expressive aphasia, motor aphasia, receptive aphasia, etc.—see Weisenberg and McBride (*Aphasia: A Clinical and Psychological Study*, New York: Hafner, republished in 1964) aphasia as a quantitative loss of language ability—see Schuell *et al.* (*op. cit.* 1964); aphasia as a loss or dysfunction of a series of psycholinguistic processes necessary for language comprehension, formulation and expression (Wepman and Jones, *op. cit.*). There has been however to my knowledge no successful attempt made to relate "type of or amount of disorder" to any recognized disease process or cortical disruption. Further, over the years since Broca's day there have been adherents to various concepts of brain function (how the neural system processes—decodes, integrates and encodes—the act of intentful verbal communication). The neurological concept of specific localization of language concepts represented by Henschen and others in the early part of the century, followed by Nielsen in the Forties and now by Luria in *Human Brain and Psychological Processes*, New York: Harper and Row, 1965. The dynamic role of specialized function in the cortex is espoused today especially in Russia and middle Europe of the present time and by a variety of neurologists and some neuropsychologists in this country. They are closest to the viewpoint that at least a disease, tumor or scar tissue known to affect a particular neural entity could indeed be held responsible for the type of aphasia demonstrable after cortical insult. Yet even in this most concretistic viewpoint of neural behavior these structuralists have not asserted that a specific type of insult would produce a specific linguistic disturbance. Thus, following almost any logic, localizationist or otherwise, any disease or traumatic neural event affecting a given area subserving a specific linguistic process would affect that process similarly as far as we know. To list all of the neural conditions, then, responsible for changes in language comprehension and use would be tautological and redundant.

In our present state of knowledge the concept of aphasia as a behavioral counterpart of a cortical event consequent and subsequent to it yet in no known way specifically tied to it still seems the most accurate statement that can be made *with any chance of empirical validation.* Diagnostic description in linguistic terms, temporally stated, with change in the description over time for the individual subject seems to be the most useful approach and by all means the most practical from the therapeutic viewpoint. The study of neurophysiology and neuroanatomical function in relation to cognitive behavior including language should be a fertile field for research and investigation, but we would be amiss if we waited until the proof of such relationships were forthcoming before we attempted rehabilitation or research in language behavior. The two aspects—etiology and behavior—can one day perhaps be put together meaningfully, but in the immediate future their relationship must be held to be tenuous in the extreme, and one aspect should not, because of its failure to demonstrate causal connection, be permitted to delay or retard progress in the other.

Insufficient evidence of any nature is presently available for a reasoned concept of *psychosocial* or *genetic* relation to aphasic processes. Both are perhaps vital to an eventual complete understanding of aphasia. Certainly neither size nor location of trauma has served to explain the vast differences in aphasic patients. Undoubtedly psychosocial and perhaps genetic factors play a role especially in aphasia in small children, so too, does pre-morbid education, personality, age and intelligence, as well as many post-morbid aspects play an equal role in the adult.

All of this preamble is to the effect of stipulating the limits of the present outline. It is based upon a description of language and integrative processes in language only. It is descriptive and time-bound in terms of the individual patient. Thus, a given patient may at one time by his capacity or incapacity to communicate demonstrate a particular level of behavior. As he moves from the presumed causative neural event in time ordinarily his linguistic behavior like his intellective and his physical behavior improves (excepting in those events of increasing neurological debilitation when the changes show a parallel decrease in efficiency and function). In many subjects these changes follow a well worn and previously travelled path thought to be not dissimilar to the stages of development of language in children (Wepman and Jones, *op. cit.*), but not always and certainly not in every particular. Thus, if one considers only free, spontaneous use of spoken language these stages are frequently seen and easily described. However, in other aspects of language use such as reading, writing and spelling, such changes as occur are often at different rates and seemingly reacquired in a different order and in a different manner than they were originally learned. Too little is really known about the acquisition of language in children to make the parallel meaningful in all of the aspects of communication. It may well be that the parallel which is presently stated purely as a hypothesis will with further study be more apparent than real. Its value lies not in its ultimate truth at the present, however, but in the guidelines it can provide for research, for prognosis and for therapy.

It may also be true, and research is needed to verify or reject the hypothesis, that what we have seen as changes in psycholinguistic processes of increasing complexity are in fact reflections of Schuell's concept of increasing complexity of a unitary function, i.e., as greater complexity is available to the disturbed cortex, as restabilization occurs, a more complex and complete linguistic processing becomes available.

Or, in Luria's terminology, it may be that the function disturbed by a lesion affecting a basic process affects all of the processes above it in the hierarchy. Then, as the area primarily affected stabilizes and becomes capable of function, the other processes slowly resume their function, never succeeding too well nor too rapidly because of the limited nature of the recovery of the basic process.

While at the present I am unable to agree with either the Schuell or the Luria concepts, both are well worth exploring in further research. My objection to the former is largely to the close relationship postulated between intellective function and its return with language function and its changes. There is too much evidence of the independence of these factors, evidence that demonstrates (1) that basic, integrative intelligence and symbolization non-verbal in nature may not be disturbed in aphasia (on-going research at the University of Chicago in preparation for publication shows a close relationship only in the global and jargon types of aphasia and no relationship with the common semantic and syntactic types). Since the two types of aphasia, the global and jargon types, that do show the relationship also are those where language feedback, affecting the decoding process, is notably absent and the latter pragmatic, semantic and syntactic types where encoding is the more outspoken disability and feedback is reasserting itself, it seems more likely that intelligence itself may not be at the root of the problem but the linguistic decoding and encoding processes and the integration that lies between may be at fault (2) that other linguistic forms of symbolic behavior such as reading, writing, work with numbers, etc. may or *may not* be affected. While Schuell's syndromes seem applicable quantitatively, far too many exceptions are seen clinically to permit at first glance a complete acceptance of the hypothesis, i.e., aphasic patients who have little or no speech but can read, write and use numbers quite adequately.

My objection to the Luria formation lies in its attempt to equate the macroscopic act of language formulation, comprehension and use as expressed in verbal command of intentful language with a specific series even though dynamically and not structurally related, of neural events. This is a postulate incapable of demonstration in our present state of knowledge; in fact it fails to explain many disturbing elements of language behavior such as the continued use of language by left hemispherectomized, right handed patients (Smith, A., Verbal and Non-Verbal Test Performance of Patients with 'Acute' Lateralized Brain Lesions, *Journal of Nervous and Mental Diseases* 141:517-523, 1965) and the growing evidence that some types of language deviations are to be observed in many right brain damaged, right handed people (Zangwill, O. L., Dyslexia in Relation to Cerebral Dominance, *Reading Disability: Progress and Research in Dyslexia*, ed. Money, J. Baltimore: Johns Hopkins Press, 1962. Archibald, Y. M. and Wepman, J. M., Language Disturbances and Nonverbal Cognative Performance in Eight Patients Following Injury to the Right Hemisphere, *Brain*, 91, Part I, 1968, 117-130). Nevertheless, the importance of the concept is such that research in this area is important and necessary.

The establishment of frequency lists of spoken language from a striated sample of normal speakers (Jones and Wepman, *A Spoken Word Count*, Chicago: Language Research Associates; 1966) now provides a base for broad scale attacks on the lexicon of aphasic adults. Some of these differences between normal and impaired speakers have been reported. (Wepman, J. M. and Jones, L. V., Studies in Aphasia: Classification of Aphasic Speech by the Noun/Pronoun Ratio, *British Journal of Disorders of Communication*, 1:46-54, 1966). These studies point to the continuing values of psycholinguistic research in aphasia leading to more adequate description of the aphasic process. The goal of this research is not in seeking etiological or causal neurological relationships but rather improved diagnostic and prognostic description as a basis not only for understanding the language disorders themselves but to provide a useful construct for rehabilitation and therapy. It is here that much research is needed providing the field of aphasia therapy with a *raison d'etre*, a structure and plan for what it has been doing relatively blindly to this time.

What is needed is imagination, ingenuity and foresightedness. Too many patients get better and too many fail to do so without our knowing why. If we knew why or even if we know only the stages through which they recovered when they do, perhaps we could begin to understand why others do not get better. What is needed is large-scale research not on the minutia of behavior of aphasic patients, valuable as that may be at some future date, but research into basic processes and change in behavior. Aphasia is not a static condition any more than a brain injured patient is static in his intellective ability. He changes and so too does his communication ability. The dynamics of these changes should be where the central effort of research should be. Longitudinal studies with broad-scale cooperation between disciplines and installations are necessary. The motto of research in aphasia should be that we think no little thought; do no little things. Language is complex so, too, must be the reasoning behind our research.

An Outline of Aphasic Symptomatology

A. Absence or limitation of language comprehension and use

  1. Inability to comprehend or use verbal symbols in the act of intentful communication

Global aphasia

Decoding and Encoding

    a) Reduction of language to automatic phrase(s)
    b) Retention of minimal facial gestures reflecting affect
    c) Lack of vocal behavior as verbal substitute
    d) Inability to comprehend or use reading, writing or other communication forms
    e) Markedly reduced if not totally absent feedback (internal and external)

  2. Inability to utilize previously learned phonemic/phonetic or orthographic patterns (morphemes) singly or in groups (phrases, sentences, etc.)

Jargon aphasia

Encoding

    a) Reduction of verbal efforts to non-word phonemic/phonetic groups
    b) Reduction of graphic efforts to meaningless unintelligible scrawl
    c) In the non-speaking child, inability to learn (retain for use) individual and grouped phonemic/phonetic graphic/graphetic patterns.

  3. Inability to regulate production of morphemes with intent

Pragmatic aphasia

(Integrative—Decoding Encoding)

    a) Speech a mixture of morphemic efforts both of good lexical form and non-morphemic (neologistic or jargon) form where end-product is unrelated or only partially related to apparent stimulus or to subject's apparent internal intent. Frequent errors in grammatical structure and agreement. Marked by absence of self-recognition of errors or of lack of communication effect (feedback, monitoring).
    b) Writing as a) above most often not attempted by subject

  4. Inability to nominate (propositionalize) with specificity the subject or direct object of one's attempted speech or writing

Semantic aphasia

Encoding

    a) Speech consists of a series of word-finding attempts especially for nouns although adjectives may also bring forth difficulty or be omitted. Frequently retained grammatical phrases of high generality, consequently less nouns than pronouns used and the latter are most often unidentified.
    Note to a) Two types of semantic aphasia with a variety of idiosyncratic characteristics in each type.

      1) Semantic defect in recovering aphasia when level of previous stage was below the semantic level at outset.

Classical Expressive Aphasia

        (a) Where there is less retention of ability to use grammatical lexicon of function words. Subject gropes for nominals without use of function words. All speech is a word-finding struggle. There is little or no fluency. Speech is telegraphic in nature because of this, but the single nominal words used are not easily or fluently produced and are often the product of constant struggle and false starts. The beginning of self-criticism is apparent. Occasional neologisms are produced and often consciously rejected immediately even though the speaker is unable to correctly substitute for them.

(b) Where the lowest level of communication disorder is the semantic level, i.e., at no time or at best for only the immediate post-traumatic period did the subject appear to have been at the no speech, jargon or pragmatic levels of language use. Here, the verbal effort is characterized by a word-finding and self-correction effort for the specific nominals, but notably there is a retention of a wide variety of relatively automatic or overlearned generalized function words and phrases used as starting devices. To the listener it would appear that speech is relatively fluent lacking only the specificity that nominals contribute to the communication art. Discomfort on the subject's part with the recognition that little specific meaning is being transmitted to his listener. Note 2 to a) Types (and perhaps stages) of semantic aphasia are recognizable to the sophisticated examiner.

(i) Nominal word-finding without success.

(ii) Nominal word-finding with some success but errors made are in production of words unrelated to the sought for word (for example, *shoe* for *house* where no cognitive, phonemic or emotional relation can be established between the word finally produced and the word expected (so called out-of-class substitution)

(iii) Nominal word-finding with some success but errors made include words of similar nature or meaning, in phonetic pattern or in emotional contiguity (so called in-class word substitution).

All of these, (i), (ii) and (iii) above are to be seen in writing, but since the subjects write less in spontaneous communication are not seen unless directly studied.

5. Inability to formulate and use grammatical structure or lexicon of function words correctly.

Syntactic aphasia

Encoding

a) Difficulty in fluency of expression where nominals are produced with some accuracy of intent but function words and phrases are omitted. Telegraphic speech (to be differentiated from semantic type by fluency of nominals—no apparent difficulty in this area, consequently no labored word-finding attempts or neologistic speech). Telegraphic because all or most functional words are omitted as in a well worded telegram.

b) Fluency of speech attained but difficulty in accuracy of use of functional words is notable.

c) Fluency relatively normal; difficulty with functional suffixes and prefixes is evident.

NOTE TO 5:

This last type of aphasia, since it is syntactic in nature, affecting only the function words and word endings, is most like normal speech and in fact cannot at times be differentiated linguistically from the efforts of the uneducated, the unintelligent or the new user of a language. Because it is the linguistic process last learned by the developing child it is the first affected and last recovered after trauma. The differentiating factor is usually based on change from an earlier more severe form in the aphasic, but without such a history in the non-aphasic. This further points to the value of studies in time rather than as cross-sections of experience. Some clues toward the last or least disturbing aspects of syntactic disability, the difficulty with tense or agreement as an aphasic process can be seen in the aphasic patient's tendency to recognize such errors and correct them when he either recognizes them or they are pointed out while the unimpaired speaker making similar errors in syntax does so without recognition and usually without self-correction even when the errors are pointed out. They are the habituated grammatical lapses which point to a failure at developing a self-critical attitude toward expression. To the aphasic they represent a disorder of language usage, to the non-aphasic they are merely his inadequate learning of the language and he rarely cares about them.

B. Absence of function or dysfunction Perceptual (recognition level) (Units—phonema/grapheme)
  1. In-put
    a) Auditory
      (1) Discrimination (least discriminable difference)
      (2) Memory span
        (a) retention
        (b) recall
        (c) sequential order
      (3) Spatial localization (Temporal)
    b) Visual
      (1) Discrimination
        (a) form
        (b) size
        (c) color
      (2) Memory span
        (a) retention
        (b) recall
        (c) sequential order
    c) Cross Modality
      (1) visual to auditory
      (2) visual to tactual
      (3) auditory to visual
      (4) auditory to tactual
      (5) tactual to visual
      (6) tactual to auditory
  2. Output
    a) Oral
    b) Graphic
    c) Gestural

Note: All perceptual level function requires recognition therefore integration. Each of the outlined functions can be differentially affected or appear in combination. A generalized perceptual disability would affect all of the functions and since they are the basis for conceptual linguistic events would also affect conceptualization. Specific perceptual disabilities, however, would not necessarily affect more than the modality affected plus the role of that modality in conceptual behavior, i.e., a dysfunction in central auditory perception affecting all of the factors involved would probably (1) retard the development of or use of speech; (2) provide an unsound phonetic/phonemic base for reading and spelling; (3) operate to reduce or retard adequate or accurate articulation. The consequences upon a child then might be seen in inadequate verbal use and learning, therefore, a lower general intelligence test score which is usually thought of as a measure of conceptual function.

D. *Clinical Aspects of Childhood Aphasia.* Some of the problems of differentiation of aphasic conditions in children—in contrast with those in adults—have already been described. Wepman's point that his "five aphasias" are demonstrably similar to developmental stages in childhood is both intriguing and useful when one undertakes to pinpoint and evaluate the problems of a particular child. So, too, is the concept of developmental aplasia, already referred to. There is little distinction in trying to deal with a childhood language disorder to describe it as *congenital aphasia*. Indeed, this is neither a good descriptive, nor a good diagnostic term; it says only that there is some kind of a disorder of language that, in a particular child, has apparently existed from birth.

On the other hand, it is scarcely true that all childhood language disorders existing from birth represent developmental aplasias. There are many sources of prenatal and perinatal, as well as postnatal, damage which may well involve one aspect or another of language function. In effect, the labelling does little and offers less in terms of information to direct management of the child and advice to his family. To this end, many efforts are made these days to try to develop a set of descriptors of function and malfunction, relative to a child's needs in developing language as these needs are presently understood. The following is an excerpt from a paper which undertakes to set up some relations between possible cause and clinically observable functions in the language disordered child. It is a reproduction of some remarks published in *Childhood Aphasia: Proceedings of the Institute on Childhood Aphasia,* edited by Robert West, sponsored by the California Society for Crippled Children and Adults, the Easter Seal Research Foundation and Stanford University School of Medicine in September 1960 at Stanford, pp. 39-44. The contributor is Dr. Wm. G. Hardy. His words are as follows:

Certain kinds of operations, however, pertinent to this reverberant cerebrospinal system, are quite clear, and from them some useful facts may be adduced. The basic problem is to try to find out something about how the CNS works in each child who is not naturally learning language.

First, it is useful to determine whether auditory discrimination and recognition take place. These are functions of the central pathways of the auditory system, dependent upon the sensitivity of the end organ.

It can be said with considerable certainty that the auditory system (probably the primary mechanism in the normal development of language-meanings) functions in terms of sensitivity, discrimination, and recognition. Sensitivity is largely, but not exclusively, a function of the conductive and sensory-neural elements of the peripheral mechanism. Discrimination involves both peripheral structures and central pathways; recognition, while dependent upon both sensitivity and discrimination, is a CNS function.

Many children are thought to be aphasoid whose only major problem is the incapacity to discriminate auditory stimuli. Without consistent discrimination, there is obvious deprivation in recognition, which underlies processing and tracking. With a breakdown somewhere in the high transmissive pathways of the central auditory system, a baby may present quite normal auditory orienting reflexes at four months of age; then, in later months, because of inability to process the detail of sound, the system may become inhibited, and he may well not respond to any sound that is causal in his environment.

This simply demonstrates one of Pavlov's well-known "laws of learning": the unreinforced stimulus (which could well be the problem with a breakdown at the cortico-thalamic level of audition) tends to produce inhibition. Some of those present have been working in this milieu with adult aphasics, and with profoundly interesting findings. When one looks for this kind of problem, he finds it daily and not infrequently with further problems in the learning of, and memory for, verbal symbols.

Both pitch and loudness are involved in discrimination and recognition. The echolalic child may well be able to handle both with a high degree of precision, and yet be so attention-distracted that he cannot remember the sequence of auditory detail relative to meaning for thirty seconds.

Second, there is needed a careful study of function in terms of auditory and visual (and tactile) pattern perception, foreground-background recognition, and related comparative activities.

Early in life, the normally developing child learns how to use an auditory self-monitoring system, a kind of servo-mechanism, which becomes the control center of his capacity to hear, to listen, and to reproduce meaningful utterances. Some children cannot naturally do this: among this group, some develop physiologic dyslalia, others are aphasoid. One of the bases for the development of this self-monitoring mechanism is the learned capacity to select the important parallels in the relation between vision and seeing, as in that between audition and hearing. The auditory experience is the more kaleidoscopic and evanescent, however, and probably more dependent upon reinforcement (what William James called "the expectancy of sameness") in the day's experiences.

It seems clear that one of the deficits of a highly distractible child who is not learning language is a fundamental inability to pay consistent attention to the succession of stimuli which makes the learning of verbal-auditory meanings possible. Possibly, this kind of differentiation involves the child's image of himself in contrast with other personalities and events. The only real connections between personalities, negotiated through our neurologic systems, are made by language and speech. Not uncommonly, we find aphasoid children who have quite as much difficulty with visual as with auditory recognition and recall; they simply cannot perform as symbolic pattern-makers. Some stimulus "out there" seems to interfere with their capacity to handle the thing that is "here."

Interestingly enough, there is oftentimes a clear familial history of problems in learning to read. Such a combination of incapacities in making relationships can scarcely be accounted for in terms of focal lacks. Rather, there must be some basic difficulties in forming patterns among perception, understanding, and recall. Various aspects of these kinds of problems can be described in terms of the child's capacities to center attention, in both vision and audition, to differentiate among different patterns, and to attend to the appropriate foreground within the distractions from the background.

An oppositive problem is that of the child who tends to fix attention, and who is therefore unable to process successive stimuli in rapid continuity. Our normal capacity to process auditory information, and to "track" it in complex succession, involves a matter of a few milliseconds per unit of information. In trying to identify the aphasic child, then, it becomes important to find out how this works with him. For instance, the handling of a few versus many units of information. Can he remember two units, but not five? Can he remember the last two units of a series of seven, but not the first three? With a child who has some verbal capacity, at least in the sense of imitative speech, this sort of thing can be well managed with the use of forward and reverse digits, or, in visual terms, with the Knox cubes.

We saw a seven-year-old a few months ago, referred as deaf, who illustrates the point:

> He has a severe auditory problem, a vicious, sharply down-dropping sensory-neural lesion which involves a major loss in sensitivity. Yet, what most bothered his teachers was his difficulty in academic learning in the face of the fact that he seemed bright.
>
> He is bright in some ways, with a nonverbal performance level of something like 120. He can read and lip-read single words. He cannot remember three forward-digits out of serial order with any combination of visual and auditory stimuli.
>
> He is deaf, as various educators use the term; he is also aphasic, and had better be taught accordingly. He is fairly good in the elements of arithmetic, but cannot describe the simplest page of Dick and Jane.

There is ample evidence that many of the classical "failures in learning to lip-read" were aphasoid children with hearing problems augmented by inability to keep tuned in on successive sensory stimuli.

The function of scanning seems vitally important to the development of verbal-auditory memory and recall. The efferent pathways of the auditory mechanism, the brain's organic listening system, are no doubt involved in this activity. The function of visual scanning is obvious in relation to rate of reading. It seems equally obvious with regard to processing auditory stimuli. The stimulus-bound child need not necessarily be hyperactive; he may be perseverative. The point is that his modes of relating himself to his environment are not free and versatile. He takes in his environment too quickly or too slowly, or inconsistently in an in-and-out fashion. In consequence, he becomes "bound" to a particular order or degree of stimulus out of context, so to speak, with the ongoing state of affairs in his environment.

At the extreme (and perhaps for relatable reasons) some schizoid children show this same kind of trouble in appraising the ongoing situation. So do some athetoid children, whose inhibitory dysfunctions keep them out of good temporal touch with successive events. There are various ways to think about this function of scanning, and to observe it. The younger the child, the more difficult the observation. One must learn how to utilize the reports of parents who are good observers: as with a little "deaf" child we saw last year; he could not respond to most environmental sounds but consistently stood near a kitchen window to appreciate the twittering of birds each morning, birds he could not see from that position. He simply fixed bird-sounds, and little else.

A final capacity (or, from the current point of view of a language disorder, lack of capacity) is what has been called tracking. This is a distinctly human attribute, as it pertains to the use of verbal symbols, probably dependent on the development of a frontal cortex. It is a matter of being able to process an indefinite variety of incoming information, employing all the attributes of the sensorium, and to relate this to previous and presently pertinent experience. With a homely simile, it is what one expects his guide to do when he is hired for a hunt. One hires him because of his reputation, and he is expected to produce; to take the hunter into the deep woods (and to get him out); to read the signs of nature; to anticipate the habits of the animals sought; to find them in the right way at the right time; and then to set up a shot the hunter cannot miss. This is tracking. In normal social intercourse, we are utterly dependent upon this nice combination of memory (stocking the storehouse with pertinent, ongoing information) and recall (taking from the storehouse what is applicable and pertinent in dealing with the needs of the current situation).

This sort of processing is the essence of verbal-symbolic capacity and use, and the lack of it is one of the hallmarks of what is called aphasia in children. Involved here is the processing in rapid temporal order of many successive bits of information. This is the essence of human learning and communication. The child who lacks this capacity of tracking is profoundly handicapped. Moreover, the use of pantomime and gesture early in life does not negate the possibility of a profound disorder in the potential use of verbal-symbolic language.

True, there are various levels of "language," but this does not mean that the levels are progressive in development, nor that one level is equal to another. The normally developing two-year-old needs only one verbal stimulus to learn a new word that is suitable in the context of his environment and experience. That our deaf children need a thousand such stimuli, and our aphasic children ten thousand, is not remarkable.

In broad generalization, we are concerned in childhood aphasia with problems of learning, memory, and recall in verbal-symbolic reference (largely integrative in normal function), the details of which can be observed by the study of various attributes of CNS function. Etiology, *per se*, is not a very useful indicator of the individual problem. This is true even when one is observing an obviously neurologically damaged child. We see many Rh-athetoid children who have auditory problems, hearing losses in sensitivity, dysacusis, aphasia, and dysarthria, alone or in combination. That somebody has diagnosed a child as an Rh-athetoid does not explain the nature of the communicative dysfunctions.

Some useful categories of clinical observations and description include:

> (1) the detail of auditory discrimination and recognition, relative to sensitivity; the integrity of these functions of hearing largely controls the usefulness of auditory stimuli in the learning of verbal-auditory language;
>
> (2) the determination of capacity in foreground-background perception contributes much to an understanding of a child's capacity to relate meaningful incoming sensory information; this capacity is largely a function of attention;
>
> (3) the fixation of attention is an opposite trait; with this tendency, the ability to manage rapidly successive stimuli is usually seriously affected;
>
> (4) a related capacity has to do with the presence or absence of stimulus-bound behavior, an inability to relate incoming information appropriately in the context of events in the environment;
>
> (5) ability or disability in tracking; this is a kind of additive function, dependent upon all the others. It is the capacity to process multiple bits of information in terms of mnemonic experience, and to organize, in recall, a response or attitude that is appropriate to the context of the situation with the use of verbal symbols. At its best, this is "verbal thinking" and adequate verbal communication. We all see many children who, say at age six years, achieve a six-year level in word-meanings, but who cannot manage the complexity of a sentence. This is a form of disability in tracking, although it is not always labelled aphasia.
>
> Such a youngster may well illustrate a kind of suboptimal function, rather than biologic deficiency. This is a distinction worthy of note. The biologic deficiency, as in the idiot, is self-limiting. The suboptimal function is commonly amenable to change through learning, though, if one wishes, a reorganization of relationships.

It seems clear that many brain-injured or maldeveloped children exhibit CNS signs of suboptimal function. These are the children with a scatter in performance which may range from 60 on some items to 120 on others. They need help, the nature of which may be outlined by means of detailed differentiation of CNS capabilities and limitations.

These must be qualified by the nature of the child's environment. The effect of deprivation of one kind or another may be powerful, indeed. Whether this exists in the form of parental guilt and withdrawal, generally inadequate stimulus, or gross suppression, the social-emotional effects may be profound. When a child cannot naturally learn what is fundamental in his biosocial existence—language and speech adequate for communication—because of suboptimal function, he typically becomes frustrated and distraught, the emotional sequellae of a severe disorder of personality.

The differentiation is important. Such effects on the deaf child, who cannot understand nor be understood, have been quite well documented. What of the aphasic child? How does he apprehend himself? What are society's images of him? Not very many years ago, the child with a cleft palate was considered an idiot in many communities, simply because his speech was strange.

What are the social images of the child who does not talk at all because he cannot remember what he hears? What do parents think about these children? What happens to parental empathy? These are matters which need extensive investigation. Public education regarding the status and needs of aphasic children, whose numbers are rapidly increasing, has scarcely begun.

It is often not too difficult to make a diagnosis of childhood aphasia, whether one is dealing with an obviously neurologically involved child or with one who is only aphasic. It is extremely difficult to convey the details of each child's capacities and limitations. A suitable descriptive vocabulary is not freely available. Moreover, much of the detail of each child's problems and capabilities must be derived from situations that might be called "diagnostic" or "creative" teaching, wherein various situations are carefully structured in order to control competing stimuli, and to learn how best a particular child may learn.

Then, too, because of common etiologic or developmental factors (genetics, intrauterine chemistry, infection, and so on), there is a high prevalence of combined problems of aphasia, of dysacusis, of motor discoordination, and of visual tracking such as may well be involved in "specific dyslexia."

A nice balance between diagnostic teaching and diagnostic reassessment seems to be a sine qua non. Even aphasic children change as a result of development and learning. The nature and detail of whatever changes occur are well worth periodic reconsideration.

E. *Brain Functioning and Language: A Historical Survey.* Reference has been made briefly to a clinical status often referred to as specific dyslexia. In careful use, this means some sort of neurologically based impairment of the capacity to read, and includes perhaps one-fifth of those with problems of reading in general. Although general reading problems may have many causes and are not always thought of in relation to human communication and its disorders (largely, perhaps, because they are commonly considered to belong within the aegis of the educator rather than the physician, or audiologist, or speech pathologist), this can scarcely obtain with specific dyslexia, a condition that is not infrequently found in conjunction with other serious communicative disorders.

Because it includes much that is directly pertinent to a discussion of the central communicative processes, including some relations with dyslexia, the following material by Dr. Douglas Buchanan has been included to furnish some historical perspective and to offer some topics for further study. The following pages are from Dr. Buchanan's chapter entitled "Development of Cortical Localization," reprinted with permission from *Dyslexia, Diagnosis and Treatment of Reading Disorders*, edited by Arthur H. Kenney and Virginia T. Keeney, pp. 11-16. The book was published in 1968 by the C. V. Mosby Company, St. Louis.

It is very difficult to establish any detailed neuroanatomy and neurophysiology relevant to dyslexia.

The earliest reference to the brain in known written history is in the Edwin Smith *Surgical Papyrus*. This is a copy made about 1700 B.C. by an Egyptian scribe. The original from which he copied may have been written by Imhotep, the architect-physician who flourished 5,000 years ago. In this incomplete copy is the first reference to the brain that is known in any human records. There are excellent descriptions of the brain, of the meninges, and of the cerebrospinal fluid and descriptions of cranial injuries and their effect on the body and on life. It is strange that the Bible has no clear description of the brain, although some historians have interpreted the silver cord and the golden bowl in Ecclesiastes as the brain and the spinal cord.

The next clear description of the brain is in the writings of Hippocrates (460-370 B.C.). He gave detailed descriptions of the effects of wounds of the head and of contrecoup injuries, and he knew that injuries to the brain had effect on the opposite side of the body.

Galen (A.D. 131-201) was a remarkable neurologist who knew the difference between motor and sensory nerves and knew the peripheral distribution of the segmental levels of the spinal cord. The story of Galen and Pausanias gives an example of his knowledge of neuroanatomy. Pausanias, the traveler, who wrote the first and still the best guidebook for Greece, appeared in Rome about A.D. 180. He complained of pain and numbness in the last three fingers of his left hand; various complicated drugs were applied to his fingers without success. Then, Galen was consulted. He was then the medical officer to the gladiators and was experienced in injuries. He put poultices on Pausanias' neck and not his hand, because the injury, he said, was at the level of the seventh cervical body. He also told Pausanias that he had injured his neck some three or four weeks before. Pausanias then remembered that he had fallen from his chariot when it had upset and that he had fallen on his back, striking his neck on a rock. This is the first record of an injury to a cervical intervertebral disk and the first record of knowledge of segmental levels in the spinal cord and of the difference in action of anterior and posterior spinal nerves.

This observation of Galen was forgotten for 1,800 years. Then, in 1943 Robert Semmes and Francis Murphy wrote their article in which they demonstrated that pain in the ulnar distribution in the left arm is not always evidence of heart disease but sometimes results from a displaced cervical disk.

After Galen, the next great figure in physiology was Rene Descartes (1596-1650). He regarded the human body as a machine that was directed and controlled by a rational soul situated in the pineal gland. His famous phrase, "I think, therefore I am," is still a part of philosophic thought, but his evidence that the pineal is the seat of the soul is less secure. Interest in the pineal has recently been revived, however, and the actions of that gland are now the subject of much modern investigation.

Thomas Willis (1621-1675) introduced the word "neurology" to the language and was the first neurologist. He described the vascular circle of the brain, which bears his name, although the plates were drawn by his close friend, Christopher Wren (1631-1723). Willis believed that control of movement rested in the corpus striatum, but he also believed that sensation was controlled by regions of the cortex.

Robert Whytt (1714-1766) of Edinburgh, who is known for his accurate clinical descriptions of tuberculous meningitis, first described a reflex in 1751. This was the reaction of the pupil of the eye to light.

Despite the work of these physicians and despite the revival of anatomy by Andreas Vesalius (1514-1564), investigation of the action of the cerebral cortex was delayed until the middle of the nineteenth century.

The three persons who first regarded the cortex as the substrate of the mind were Emmanuel Swedenborg (1688-1772), Franz Joseph Gall (1758-1828), and Sir Charles Bell (1774-1842).

The idea that the animal body was built of cells, as was a plant, did not appear until Theodore Schwann (1810-1882) demonstrated this in 1839.

This most fundamental contribution was given by Schwann in a rather offhand way in his monograph on the microscopic structure of animals and plants.

For centuries the brain was believed to be a solid organ of uniform structure. The first attempt to give cerebral localization of function an anatomic foundation was made by Franz Joseph Gall (1758-1828) and his pupil Johann Spurzheim (1776-1832). In the time of Gall, anatomy of the brain was mainly concerned with the white matter, because white matter did not decompose so rapidly and was easier to work with than the gray matter. The gray matter was believed to be part brain and part body, for it was believed to consist mainly of small secreting glands. The white matter was regarded as the functional center of the brain, the seat of thought and of emotion. Gall suggested that the brain was a very complex organ with many parts and systems each with a specific function, and he believed the cortex to be the locus of thought and of the mind. The excellent anatomic work of Gall was, unfortunately, soon lost in the theatrical errors of phrenology.

During this same period Luigi Rolando (1773-1831) studied the effects of ablation of portions of the cerebrum and the cerebellum. He worked on the island of Sardinia with small animals, and he concluded that the cortex initiated voluntary motor activity and that the cerebellum controlled involuntary activity.

Marie Flourens (1794-1867) repeated Rolando's work and made an excellent contribution to the physiology of the cerebellum. His major error, however, was his belief that there was no specific motor area in the cortex and no division of the cortex into different functional units. This agreed with the opinion of most scholars, who believed that perception and the mind were too elaborate and specialized to have any vulgar anatomic substrate in the brain. Flourens was elected to the Academie des Sciences, an honor refused to Gall, because Flourens' error was accepted as truth and Gall's idea that thought was related to the cortex was regarded as wrong. Flourens continued to succeed, and in 1840 he was elected to the Academie Francaise, defeating Victor Hugo in the election. Flourens' error was still acceptable while Gall's anatomic reputation steadily diminished, but the proof of Gall's ideas about the functional differences in various parts of the cortex came soon after.

The cerebral cortex of the adult human brain has an area of about 2½ square feet. In this area there are blood vessels and special cells, neurons, and the glia. During the Middle Ages there were interesting calculations of the number of angels who could stand on the point of a needle. Somewhat better calculations suggest that the cortex contains about 14 billion neurons. The other cells are astrocytes, oligodendrocytes, and the cells of the microglia. The number of these cells is unknown but is many times that of the neurons. Some of the astrocytes are the servants of the body of the neuron, and the oligodendrocytes care for the myelin sheath covering the axon. These glial cells have a life of their own, as was first suggested by Ramon y Cajal (1852-1934). They can move from place to place and can reproduce themselves. The neuron sits like a Buddha in a cave, the protoplasm of the cell body constantly streaming. At irregular intervals the neuron belches, and chemical changes and electrical discharges flow down the axon.

In man, cell division of the neurons of the cerebral cortex is complete by the fifth fetal month, and at that early time in life the number and quality of these important cells is permanently determined. Any neurons that are destroyed by injury or by disease are not replaced by other neurons. Injured neurons are removed by the microglia, which engulf them and carry them to the nearest venous system. Their place is filled by astrocytes and astrocytic fibers. All treatment and all prognosis in neurology must recognize this fact. It may seem strange that the neuron, the most important cell in the body, cannot be replaced, but, if replacement were possible, memory could not exist and language and learned actions would have to be relearned every few months. Since the glia retain the power of reproduction and the neurons do not, most neural tumors of the brain consist of abnormal glial cells and there are very few tumors of abnormal neurons.

Localization of function in the cortex started with the work of Jean Bouillaud (1796-1881) and his pupil, Pierre Paul Broca (1824-1880). Both men were intensely interested in speech, in reading, and in writing. Bouillaud claimed that speech disorders always had the associated lesion in the frontal lobe. Paul Broca in 1861 demonstrated the brain of his famous patient, Tan, who had suffered for many years from aphemie, renamed phasia by Armand Trousseau (1801-1867). There was a lesion in the left frontal lobe, in the third left frontal convolution; this soon became known as Broca's convolution.

It was not until some years later that Broca realized the significance of the left cerebral hemisphere in speech. The concept of unilateral cerebral dominance had been proposed by Marc Dax (c. 1770-1839) of Montpelier in 1836, but his writings were not published until 1877.

Forty years after Broca's demonstration, Pierre Marie (1853-1940) re-examined the brain of Tan and found parietotemporal lesions as well as the lesions in the frontal lobe. Despite these faults, Broca's reputation remains as the first to attempt functional localization in the cortex.

Carl Wernicke (1848-1905), when only 26 years old, published a small monograph on aphasia in which he described sensory or receptive aphasia and localized the related lesion in the posterior part of the first temporal convolution of the left hemisphere.

The first recognition of a structural organization within the cortex came in 1776, when Francisco Gennari (1750-c. 1795), as a medical student, noticed a white line running through the cortex in the occipital region. This was soon confirmed by Felix Vicq d'Azyr (1748-1794), but only later was it realized that this was the visual center.

Seventy years later, in 1840, Jules Baillarger (1806-1891), French psychiatrist, cut thin layers of the cortex, placed them between glass, and illuminated them from behind. Then he saw the cortex divided into six layers of alternate white and gray laminae.

Another 25 years passed before microscopic study of the cortex was started by Theodor Meynert (1833-1892) and expanded by Ramon y Cajal. At the beginning of the twentieth century general schemes and maps of the architecture of the cortex were evolved by Alfred Campbell (1868-1937) in 1905, by Korbinian Brodmann (1868-1918) in 1908, and by Constantin von Economo (1876-1931) in 1925. The most recent study of the cytoarchitectonics of the human isocortex was published in 1951 by Percival Bailey and Gerhard von Bonin.

The experimental approach to the neuroanatomy and neurophysiology of the cortex came soon after the development of electrical methods of stimulation. The famous team of Eduard Hitzig (1838-1907) and Gustav Fritsch (1838-1891) investigated the excitability of the dog's brain. They displayed the anatomic limits of the motor strip and finally disproved Flourens' belief that the cortex was not excitable.

David Ferrier (1843-1928) demonstrated with precision the cortical regions in the monkey that were excitable to electrical stimulation. He was a pupil of John Hughlings Jackson (1835-1911), and by experiment he demonstrated the truth of Jackson's belief that there were areas in the human cortex where movements of the limbs were represented. Jackson had concluded this from his skillful and thoughtful observations of the actions of patients with convulsions.

The first recorded electrical stimulation of the human brain was done by Roberts Bartholow on the twenty-sixth of January, 1874. The patient was Mary Rafferty, 30 years old, a native of Ireland, and a patient in the Good Samaritan Hospital in Cincinnati, Ohio. In both parietal regions of the skull there was erosion of the bone with exposure of the dura. Both galvanic and faradic stimulation were used, and Bartholow observed that no pain was produced by needling of the brain substance and that stimulation of the parietal regions produced movement of the arm and of the leg on the opposite side. The most detailed and accurate observations of the effects of stimulation of the human cortex were made by Harvey Cushing (1869-1939) in 1909 during operations with local anesthesia upon two patients who had suffered from convulsions.

The corresponding observations on the cortex were the early recording of the spontaneous electrical activity. This was first done by Richard Caton (1842-1926) in Liverpool in August, 1875, with the living rabbit brain, using a galvanometer as the indicator. He found that "feeble currents of varying direction pass through the multiplier when the electrodes are placed on two points of the external surface, or one electrode on the gray matter and one on the surface of the skull."

Hans Berger (1873-1942) of Jena in 1925 made the first recording, through the intact skull, of the spontaneous electrical activity of the brain in man. This was the original electroencephalogram.

Campbell described 20 cortical fields, Brodmann increased the number to 47, and von Economo, to 109. Brodmann's cortical map is still most widely used; the areas that may be related to visual perception in dyslexia are areas 17, 18 and 19. The region of the cortex called the angular gyrus is also frequently referred to in writings about dyslexia.

If identification of an area of the brain that was specifically related to reading was possible, it might then be possible to devise a test which would reveal a lesion in that region. Demonstration of such a lesion would help to diagnose dyslexia, although failure in identification would not necessarily exclude it. Unfortunately, such an anatomic locus has not been recognized nor the specific test devised.

The angular gyrus is a region of the cortex frequently described in anatomic writings about dyslexia. It surrounds the terminal portion of the superior sulcus of the temporal lobe. The relation of the superior sulcus to reading was first recognized by Joseph Dejerine (1849-1917). In 1892 he described an adult who, after an intracranial vascular accident, lost the ability to read but still could write. Postmortem examination of the brain revealed an infarct in the angular gyrus.

Another less specific reference comes from the work of Paul Flechsig (1847-1929) on the process of myelination of various regions of the brain. He demonstrated that, in the cortex of the angular gyrus, myelination comes later than in the neighboring regions. If myelination were unduly delayed, this might give an anatomic basis for developmental dyslexia. It might also explain why some children with dyslexia tend to improve as they grow older. This is a neat and attractive theory, but there has been, as yet, no demonstration of its truth.

Many animals, including man, have paired cerebral hemispheres joined by the corpus callosum and connecting commisures, so that there are two, third frontal convolutions and an angular gyrus on both sides. The reason for the double brain and for the crossing of most of the pyramidal fibers is still uncertain, although the reversal of an image on the retina and the crossing of visual fibers in the optic chiasm are probably involved. To this double innervation there is added the complication of the dominance of one cerebral hemisphere over the other. Most people are right-handed, and most have the anatomic basis for speech in the left hemisphere. But it is by no means clear that this left hemisphere dominance is usually present in the physiology of reading. Knowledge of representation of intellectual functions in the cortex is still vague, contrast studies of the brain are crude, and electroencephalographic tracings are complicated and variable. Because of these difficulties there is as yet no objective test that can display an anatomic or physiologic lesion underlying dyslexia.

IV. Some Key Questions Concerning Gap Areas in Language Disorders

Each of our consultants has offered some suggestions about further research and study of various aspects of the "central process" in human communication and its disorders. Dr. Neff outlined some unanswered problems in terms of neuroanatomy and related behavior with particular emphasis on sensory storage of information in brief intervals of time. Dr. Masland expressed particular concern about the need to further refine and differentiate (or at least to understand better) the functioning relations between the two hemispheres of the cortex. Dr. Schuell offers many suggestions, particularly the need somehow or other to set up systems whereby the use of particular steps in treatment of adult aphasic could be controlled and studied in a reasonably objective fashion. Dr. Wepman emphasizes the need to recognize the dynamics of an aphasic state, and therefore the need to refine clinical steps in description of the affected person. This calls for longitudinal studies and thoughtful cooperation in depth among several institutional centers where interest and facilities are available. Recurrent throughout all these discussions is the thought that more refined descriptors are needed, descriptors which can be related directly and well with clinical operations.

Many other suggestions have been made by various experts consulted in the course of these inquiries. Some of these have been re-expressed to fit the general design of the report; others have been recorded verbatim.

The questions that follow are intended to express a kind of broad view about research still to be done in order to provide some answers which can hopefully be applied to alleviate these very serious problems and to provide a better baseline of information about normal function.

A. *Can linguistic encoding functions be separated from those for decoding?* Historically, in attempts at classifying aphasic disorders in adults, they have been dichotomized into intake and output impairments. Terms have varied: e.g., sensory and motor aphasia; receptive and expressive; evaluative and productive and, more recently, decoding and encoding. Is there any firm basis for believing that virtually all aphasic involvements may not be varied expressions of an underlying impairment for intake? Does Pierre Marie's postulation hold that Wernicke's syndrome is the only true type of aphasia, and expressive involvements are anarthrias and/or apraxias? Can Luria's concept of the analytic-synthetic centers for language be reconciled with Marie's postulation? Would this be a fruitful line of approach in studying aphasic involvements in adults? What are the implications for the understanding of developmental aphasia in children?

B. *Is there a need to distinguish between expressive involvements and apraxias? Is there any possibility of the existence of a motor involvement without sensory or integrative problems (impairments)?* These questions are corolaries to the previous one. Are apraxic involvements those impairments of voluntary execution of previously established acts—manifestations of underlying CNS disturbance? To what extent is the patient's lack of confidence in his intake expressed in his impaired output? May apraxic involvements be considered in part to be a lack of security arising as a product of impaired intake, and so become an expression of sensory-integrative activity? May Luria's concept of the analytic-synthetic centers be understood in the light of the above?

C. *To what extent would it be fruitful to understand aphasic involvements as contrasts in the position of:* 1) *Schuell's quantitative postulation;* 2) *Wepman's modality bound postulation; and* 3) *Luria's position as to impairment in the functioning of analytic-synthetic centers?* May the observations (findings) of Schuell, Wepman, or Luria be used to support all three positions? Do the postulations have differential implications for the treatment of adult aphasia? For developmental aphasics?

D. *What are the behavioral implications for children when a second signal system (Pavlov-Luria) fails to develop?* In his *Higher Cortical Functions in Man* (New York: Basic Books, 1966, p. 34) Luria states and quotes Pavlov as follows:

> "The fact that the speech system is a factor in the formation of the higher mental functions is their most important feature. Because of this, Pavlov was justified in considering the 'second signal system,' which is based on speech, not only 'an extraordinary addition, introducing a new principle of nervous activity,' but also 'the highest regulator of human behavior' (Complete Collected Works, Vol. 3, pp. 476, 490, 568-569, 577)."

Further, Luria observes (op. cit., p. 85):

> It has been advanced . . . that the higher mental functions of man are functional systems, social in origin and mediate in structure. This primarily means that no single complex form of human mental activity can take place without the direct or indirect participation of speech and that the connections of the second signal system play a decisive role in the formation of these activities.

Have we any reliable observations about the behavior of children who, at given ages (e.g., six-month periods beyond age eighteen months) are without functional speech and for whom a second signal system has failed to develop? Is the child who develops a gesture system different behaviorally from the child who has no such system? (If there are differences, does this become the basis for an argument that it would be advisable to teach a gesture system first to children who cannot readily learn an oral system of language?) What are the implications for the cognitive development of the child? At what age do autistic manifestations become manifest to a degree that they constitute a problem in treatment? How do children with relative late onset of speech (after thirty months) but who speak acceptably by three to three and a half years differ in their behavior from children who continue to be severely retarded in language development up to and beyond four years of age? At what age does it become difficult to distinguish the childhood aphasic from the childhood schizophrenic?

E. *What is the evidence that primary autism (Kanner) is related to CNS involvement?* The behavior of non-verbal children with primary autism suggests that they are dependent and respond to proximate stimuli (direct bodily contact—primitive stimulation and reaction). Conversely, the child with primary autism seems to have an impairment for distance reception and so presumably processing of events through distance reception (eyes and ears). May we therefore postulate, as does Rimland in his book *Infantile Autism,* New York: Appleton-Century-Crofts, 1964, that there is an underlying CNS involvement (reticular system) for visual and auditory (distances/events)? If there is a CNS involvement, reticular system or elsewhere, is it on the basis of delayed maturation or acquired (pre, para, or post-natal) pathology? Are we able to reproduce quantities of visual and/or auditory material after minimum exposure (opportunity for learning) with the failure of the children to formulate and produce meaningful language? Are children with primary autism able to reproduce only when decoding is not involved, when in mirror-fashion they can reflect without thinking? These notions are implied in Rimland's hypothesis that ". . . the reticular formation is the site at which sensory input (and perhaps also imaginal input), represented as highly complex electrical patterns, is integrated and converted to a code which makes it compatible with the retrieval system used in making available a wide range of the content of memory."? (Rimland, op. cit., 193-194).

F. *Is there a possible relationship—a common etiology—that may explain an adult's jargon aphasia and the developmental jargonic problems of children?* Does an adult who engages in jargon hear speech as jargon, or is the jargonic flow a failure of monitoring his own speech despite relatively normal reception? Is the agrammatism that often characterizes jargon, and perhaps the entire jargonic flow a manifestation of a basic syntactical disturbance? Does the child who maintains jargon speak as he hears, much as an adult hears a foreign language with which he is not familiar as a flow of unidentifiable non-phonemic utterance? May both the adult's and child's jargon be explained by Luria's concept of an impairment for phonemic analysis, presumably on the basis of a defect of the auditory cortex that results in a breakdown of auditory analysis (adults) or a failure to develop auditory analysis (childhood developmental)?

G. *Are there any characteristic intellectual and behavioral manifestations in a child who developed normally and presumably depended upon language to monitor and control his behavior and then, as a result of cerebral pathology or trauma, experienced an interruption and disruption in his monitoring-control system?* Assuming ages 12-13 as the upper age range for "cerebral plasticity" and shift of dominance for over-all language control, what factors other than age (e.g., handedness, familial tendencies for laterality, intelligence, nature of insult) are related to reorganization of the CNS and resumption of language control? Is there a difference in reestablishment of control for the child who has incurred a vascular accident and one who has incurred external trauma? (Penfield and Roberts in *Speech and Brain Mechanisms,* hold that ". . . plasticity of the brain as a result of vascular disease is not different from that occurring after trauma." *op. cit.,* 154).

Are there intellectual detriments associated with increasing age of the occurrence of the insult? At what age does the general picture of the child tend to resemble—regress to—developmental aphasia? At what age does the general picture tend to resemble adult aphasia?

H. *What are the implications of the individual's premorbid personality traits (inclinations, "attitudes") and psychological-social factors (home environment, family relationships) for the maintenance of aphasic disorders in adults?* Are there any differences related to the pathology associated with the onset of aphasia (vascular, traumatic, neoplasm)? Are there any differences related to the aphasic manifestations? Is there any evidence to support Goldstein's position that aphasias are a manifestation of a loss of abstract attitude, or of Eisenson's position that maintained aphasic involvements are often an *aggravation of an underlying pre-morbid inclination* toward concretism and ego-orientation? Of what significance is the factor of age *per se* in the expression and maintenance of aphasic involvements? Does early therapeutic intervention rather than waiting for evidence of spontaneous recovery reduce the likelihood of the development of concretism and ego-orientation in the middle-aged and older aphasic patient?

I. *Why is the normal child able to understand language formulations he has not heard before and to generate sentences that he has not produced before?* (Chomsky). May the generating of language formulations and the understanding of "new" formulations be explained on the assumption that what a normal bright child learns is what the specifics he is taught represents, whereas a mentally slow child learns precisely what he is taught? Does this generalizing-generating ability distinguish the brain-damaged child who below age five or six tests (psychometrically) at about average from the older (above age 6) child?

J. *What is paraphasia?* In order to understand paraphasia in adults is it necessary to appreciate that all language disruption may have psychodynamic features, or, at least, that at a given moment of linguistic involvement an aphasic is not without individual psychodynamics? How useful is Freud's explanation of slips of the tongue in the understanding of paraphasia? May some paraphasic errors—particularly those limited to word distortions—be explained as a contamination of semantic and phonetic features in the aphasic's associations and generalizations in language processing? (Luria, op. cit.)

K. *In young children, is there any determinable relationship between the quantity and quality of verbalization at home and a child's failure to develop adequate verbal behavior?* Obviously, these matters involve some sort of hypotheses about psychosocial deprivation. This is the keystone of the concept of Operation Headstart, among other kinds of related activities. On the face of things, it seems apparent that many instances of retarded development of speech and language (and, later on in the child's life, various kinds of reading disabilities) may be aggravated, if not caused, by psychosocial deprivation. Anybody who works diligently with the clinical problems of children with disorders of communication is well aware of the frustrations and general disturbance shown by many of them by the age of two or three years. As yet, however, there are no categorical studies to help document the nature and possible directions of deprivation of adequate verbal stimulus. It may well be that some of these kinds of problems are relatable to those of the many children with "soft" neurological signs.

L. *How can we develop the means to make a reliable estimate of the number of children with various kinds of disorders attributable to CNS problems (exclusive of hearing loss and general retardation)?* This is in part a matter of definition, and in part a matter of epidemiology. There is much current interest in the kinds of CNS problems which exhibit only "soft signs" to the neurological clinician. They are described in many different ways. More often than not, the etiology is obscure or unknowable. Apparently, few of these children can be subject to cure. Two points, then, seem to be important: (1) the capacity to determine the nature of the problem early in the child's life; and (2) appropriate placement in training for him, so that he may learn to the best of his capacity. The more complex the syndrome, the more difficult will be both description and placement. The many children from the epidemic of prenatal rubella in 1963-64 provide many thousands of cases in point. These children have so many symptoms of so many kinds of complex involvements that the fact they are "deaf" or have language disorders is often overlooked.

M. *What is the "natural history" of language disorders? What is the "natural history" of the development of language?* The general topic of language disorders in young children requires much illumination. Any qualitative or quantitative assay of these children becomes only the more complex, because of the dearth of descriptive norms applicable to all children in terms of the development of language. Among the "abnormal" children who do not naturally develop language—and exclusive of those who are deaf or who are intellectually retarded—are many who have problems related to the auditory system, or to the integrating functions of the brain in dealing with acoustic stimuli. Cognate dysfunctions include peculiarities of attention, and difficulties in storage and recall. Some of these problems in early childhood have been thought about as "developmental aplasias," (Wepman, *op. cit.*, 1963; Hardy, *op. cit.*, 1965) involving retarded or incomplete structures and functions, while others are more specifically related to brain injury, "minimal" or otherwise. Very little is known about causal relations, particularly relative to the developmental deviations. There are ever-increasing numbers of these children.

A basic problem is that we do not as yet know how children learn a language that is native to them.

N. *Is there any relation, or gradation of relationships, concerning the use (or lack of use) of acoustic feedback among autistic, aphasic, and hard of hearing children?* At first glance, this question appears to be abstruse and vague. In point of fact, however, a possible array of relationships here—well documented and controlled—would go far toward lightening the arduous task of differential diagnosis of children with these kinds of communicative disorders. Rarely do the children come with neat describable problems—at least, not those with severe behavioral and language disorders. Yet, a common dysfunction within these three categories is lack of, or inconsistent, response to sound. We know that a moderate-to-severe hard of hearing child has some acoustic feedback, albeit limited and distorted. We cannot be quite so sure about the "autistic" child who does not talk, and who does not consistently demonstrate verbal understanding; nor about the child who has what is sometimes called "sensory aphasia." With them the acoustic feedback may be highly variable, and therefore quite unreliable. With all the present concern for theories and facts of a servomechanism (acoustic, mechanical, and physiologic) there has been little work on the specifics that might well apply to differential diagnosis, and to long-term prediction of a given child's needs and potentials.

V. CONCLUDING STATEMENT

Obviously, there is much more to be said about the "central process" than has been included in this chapter. Some generalizations have been made about anatomic and physiologic status in terms of present knowledge. Attention has been paid to current information about the neurologic substrates of language and speech, and to psychophysiologic aspects of sensory function related to the central functions. Special attention has been given to different attitudes, and philosophies about aphasia and related disorders of language, and some attention to dyslexia (which only fairly recently has come under more extensive study). Attempts have been made to differentiate and to relate similarities between language disorders in children and adults. Various simple and complex questions have been put forward in an attempt to underline certain aspects of research needs. Much more could be added in terms of the acquisition and development of language: the contribution of psycholinguistic models; relations between communicative problems and learning theory; developmental trends in study of linguistic features (vocabulary, syntax, meaning, and so forth); and some of the psychosocial correlates of language development (economic status, cultural deprivation, and so on). There is much to be said about the problems of learning a second language, and about various kinds of gesture language. Interesting as all these topics may be, however, they tend to lead one somewhat away from a concentration on neurologic aspects of the field of human communication and its disorders, which is the basic mission of this undertaking.

A considerable amount of attention has been paid to various problems of management; more to rehabilitation than to habilitation. It is somewhat easier to reason about the problems of the adult who has had normal language and speech than about those of the child whose basic problems constitute a fundamental learning disability. Little can be said, as yet, about prevention except in the sense of secondary prevention, wherein one would undertake to protect the affected individual from some of the unwanted and undesirable effects of trauma, disease, or maldevelopment.

Most of the consultants with whom these problems have been discussed are in agreement about the need for two major kinds of study: (1) basic neurophysiologic correlates of behavior that relates to language comprehension and use; and (2) multiple, interdisciplinary, and interinstitutional longitudinal studies of affected persons and groups of persons.

Chapter 5—RESEARCH ON SPEECH PRODUCTION

I. INTRODUCTION

The procedures used in developing this chapter were similar to those described in the introduction to Chapter 3. An outline was developed and submitted to selected authorities. The comments and summaries provided by these consultants constituted a major source for the material contained in this chapter. As in the case of Chapters 3 and 4, space limitations dictated that these materials had to be abstracted and distilled for inclusion in this chapter. However, the contributions of all consultants were helpful and the committee is indebted to their efforts.

Despite the fact that for most persons the processes of speech production are so nearly automatic and carried out with so little conscious effort that we tend to take our ability to speak entirely for granted, a relatively small amount of reflection will convince one that the processes of speech production are, in fact, highly intricate and complex. Brief consideration of a few simple models representing different phases of the speech production process will serve both to emphasize the complex nature of this process and to help in defining the scope of our concerns in this chapter.

The first such model is that contained in Figure 5-1. This diagram, which has been borrowed from the book entitled *The Speech Chain* by Peter B. Denes and Elliot N. Pinson (Bell Telephone Laboratories, 1963), shows that the spoken message must exist in several forms in order to be communicated from the mind of a speaker to the mind of the listener. At the first level the speaker organizes his thoughts and ideas into linguistic form by selecting appropriate words and ordering them in accordance with the syntactical rules of his language. At this level, also, a process of analysis and organization must occur which produces a program of neural impulses capable of initiating and controlling the precisely organized and coordinated neuromuscular activities of the respiratory, laryngeal, and articulatory mechanisms that are required for the production of speech. This complex, but very nicely coordinated, series of neuromuscular events is designated as the physiological level in the Denes and Pinson diagram. As a result of these events the acoustic signal which is shown on the third level is generated. It is a significant feature of this diagram that the acoustic signal is shown as the stimulus for the feedback link by means of which the speaker is able to monitor, and presumably thus to control to some degree, the processes of speech production. A more complete diagram would show an additional feedback link which channels tactile and kinesthetic information arising within the speech organs back to the central nervous system where it can serve to aid in the control of speech output. In this chapter our concern will be primarily with the physiological level of the message, as here designated by Denes and Pinson. However, we will necessarily be concerned with the acoustic effects of such physiological activity; and we will also be concerned with some aspects of what they have designated as the linguistic level, since the central nervous system activity by means of which the peripheral neuromuscular events are programmed, initiated, and controlled are a necessary part of speech production processes.

Figure 5-2 is an attempt to represent a somewhat more detailed conceptualization of certain phases of the speech production processes. This diagram, which emphasizes the relationship between the acoustic signals of speech and the neuromuscular activities which are required to generate them, provides a more detailed representation of the assumed relationship of the muscular movements of speech production to the underlying neural activity. Figure 5-2 also stresses the monitoring and control of the physiological events of speech production by means of information fed back to the nervous system via the tactile and kinesthetic sensors as well as the auditory sensory system.

Finally, the scope of our concern in this chapter can be somewhat further specified by consideration of the functions which are performed by the several parts of the peripheral speech mechanism. Table 5-1 shows the division of the peripheral mechanism into three parts: respiratory mechanism; laryngeal mechanism; and the vocal cavity system. The table also specifies in a very general way the speech and voice functions performed by these various divisions of the peripheral mechanism. It is to be understood, of course, that the separation of the speech production mechanism into three divisions as shown in Table 5-1

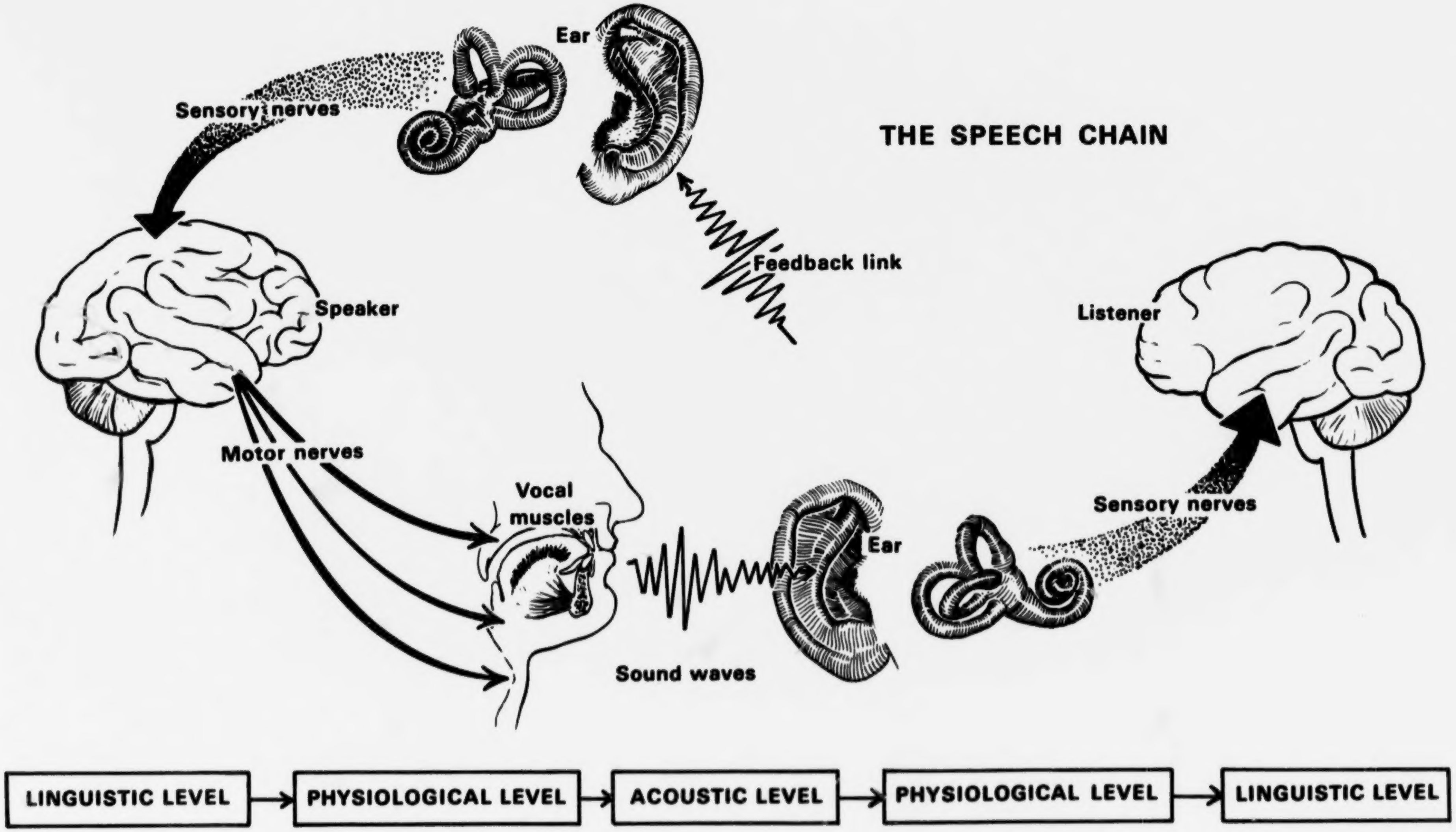
THE SPEECH CHAIN
Ear
Sensory nerves
Feedback link
Speaker
Listener
Motor nerves
Vocal muscles
Ear
Sensory nerves
Sound waves
LINGUISTIC LEVEL
PHYSIOLOGICAL LEVEL
ACOUSTIC LEVEL
PHYSIOLOGICAL LEVEL
LINGUISTIC LEVEL

Figure 5-1. The Speech Chain showing the different levels and the different forms in which events corresponding to a spoken message must occur as the message progresses from the mind of the speaker to the mind of the listener.

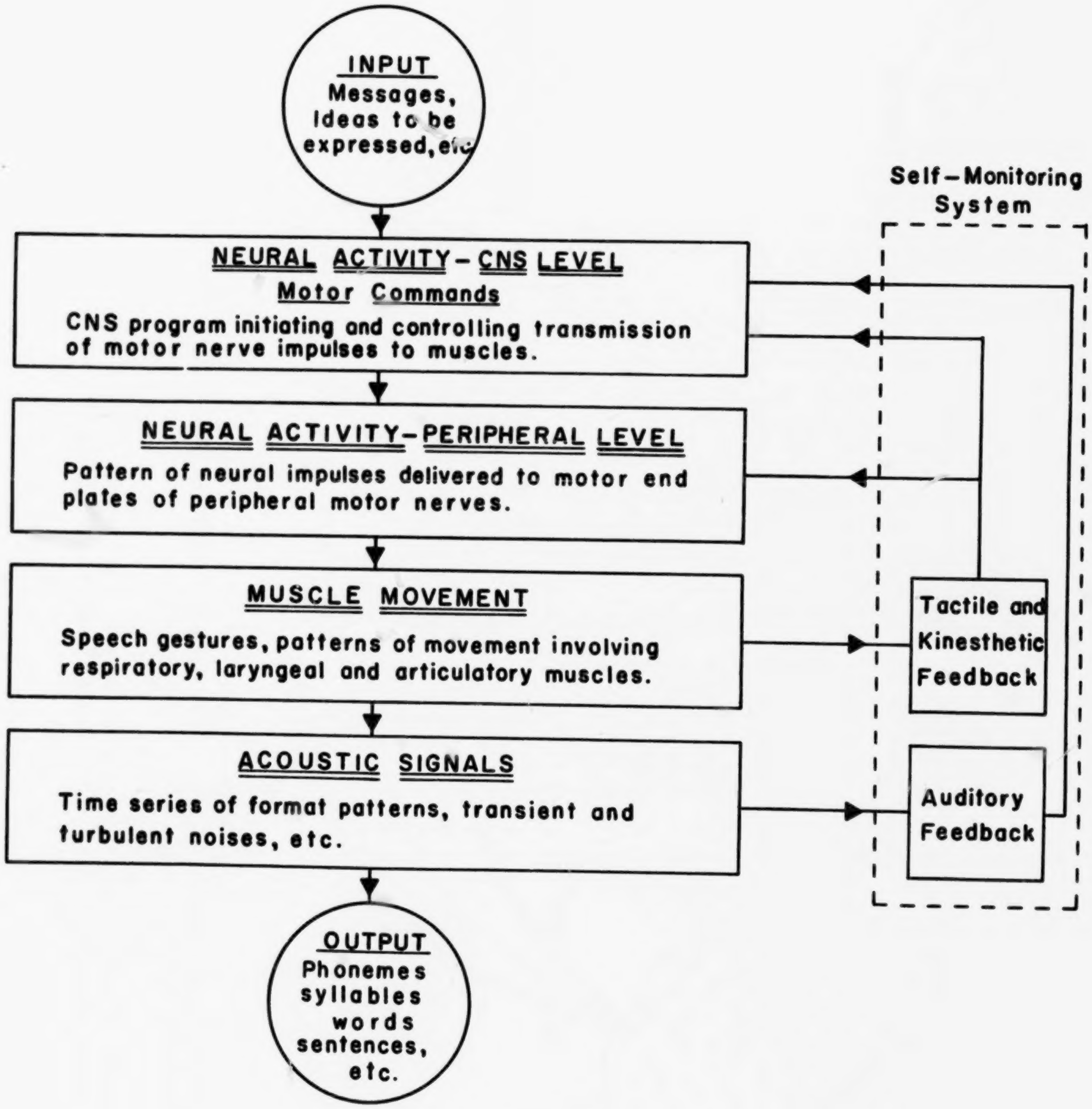
INPUT
Messages, Ideas to be expressed, etc
Self–Monitoring System
NEURAL ACTIVITY – CNS LEVEL
Motor Commands
CNS program initiating and controlling transmission of motor nerve impulses to muscles.
NEURAL ACTIVITY – PERIPHERAL LEVEL
Pattern of neural impulses delivered to motor end plates of peripheral motor nerves.
MUSCLE MOVEMENT
Speech gestures, patterns of movement involving respiratory, laryngeal and articulatory muscles.
Tactile and Kinesthetic Feedback
ACOUSTIC SIGNALS
Time series of format patterns, transient and turbulent noises, etc.
Auditory Feedback
OUTPUT
Phonemes syllables words sentences, etc.

Figure 5-2. Diagram showing one conceptualization of the neuromuscular activities required for the generation of speech.

TABLE 5-1. Divisions of Speech Production System and Their Respective Functions for Speech.

I. RESPIRATORY MECHANISM

A. STRUCTURES	B. FUNCTIONS
1. Thoracic cavity	1. Generates expiratory air pressures and flows required at the larynx for phonation.
2. Lungs and tracheo-bronchial tree	2. Generates oral air pressures required for consonant articulation.
3. Neuromuscular systems which control the volume of the thoracic cavity	3. Participates in control of pressure and flow required for regulation of vocal pitch and intensity and to divide speech into syllables, phrases, etc.

II. LARYNGEAL MECHANISM

A. STRUCTURES	B. FUNCTIONS
1. Larynx (cartilages, folds, membranes, ligaments, etc., both intrinsic and extrinsic).	1. Vocal fold vibrations provide quasi-periodic sound source during voice production.
2. Neuromuscular systems for controlling adduction-abduction, lengthening-shortening, stiffening (tensing) and relaxing of vocal folds and for controlling gross movements of the larynx as a whole.	2. Laryngeal adjustments coordinate with intratracheal air pressure regulation to control vocal pitch and vocal intensity.
	3. Vocal fold action determines input acoustic spectrum to vocal cavities thus setting basic voice quality characteristics.
	4. Valving action assists in regulation of air flow during both consonants and vowels.

III. VOCAL CAVITY SYSTEM

A. STRUCTURES	B. FUNCTIONS
1. Pharyngeal, oral and nasal cavities. a. Pharyngeal walls b. Epiglottis c. Tongue, jaw, lips, hard and soft palate d. Etc.	1. Articulation of vowels by a. Shaping of oral-pharyngeal tract to regulate resonance properties of tract b. Controlling coupling to nasal cavities
2. Neuromuscular systems controlling movements of the tongue, jaw, lips soft palate, pharyngeal walls, etc.	2. Articulating consonants by a. Generation of continuous spectrum noise by constricting air flow at various locations in oral tract b. Generation of transient noises by stopping and sudden release of air flow at various oral cavity locations c. Regulate coupling to nasal cavities d. Control shaping of oral-pharyngeal tract to regulate resonance properties
	3. Assists in regulations of air flow through valving actions
	4. Participates in regulation of voice quality and vocal intensity

is a convenience based primarily on anatomical considerations, and has only limited relevance to function. Functionally, the entire speech production mechanism is a complex, interrelated system requiring precise coordination of its various parts. Thus, for example, the process of phonation involves not just the larynx, but coordination of laryngeal activity with the control of the expiratory air stream which is generated by the activity of the respiratory mechanism. The control of the pitch and intensity of the voice likewise depends on a complex interaction between adjustments of laryngeal musculature and adjustments of the expiratory pressures and air flows generated in the respiratory mechanism. To account for the particular tone quality, or timber, of the resulting vocalization, one must also take into account the resonance characteristics of the vocal cavity transmission system formed by the pharynx, oral cavity, and nasal passages. In a similar manner, it may be shown that the utterance of consonant sounds also depends upon the complex interaction of all three divisions of the speech production system.

This chapter attempts to present (a) a digest of contemporary knowledge concerning the speech production mechanism and the pathological states affecting this mechanism which may result in speech or voice disorders, and (b) a summary of needs for further research and educational development in relation to this branch of knowledge. The chapter will be developed in relation to the following major headings: normal speech production systems and processes; pathologies affecting the speech production systems; speech disorders without known organic etiology; management and treatment; and training needs. It will be understood that space limitations have forced the omission of many details, and much of the discussion is necessarily a statement of conclusions without full development of supporting evidence. If, despite these limitations, we have succeeded in presenting a reasonably comprehensive and unbiased overview of the current state of knowledge and our needs for further research and educational development, our purpose shall have been served.

II. NORMAL SPEECH PRODUCTION SYSTEMS AND PROCESSES

A. *Status of Contemporary Knowledge.*

1. Anatomy of the Speech Production Mechanism. Structures with which we are here concerned include: (a) the respiratory mechanism, i.e., the lungs and tracheal-bronchial tree, the thoracic cage and the muscles of the trunk which control the expansion and contraction of the thoracic cage; (b) the larynx including its extrinsic connections and attachments, e.g., the strap muscles connecting it to the sternum and hyoid bone; and (c) the structures of the head and neck which form the pharynx, oral cavity, and nasal cavity and which are involved in the movements of the tongue, jaw, lips, soft palate and pharyngeal walls. It is obvious that all of these structures have other functions than those of speech and voice production and consequently have been studied extensively as part of the general study of human anatomy. In Chapter 3 it was stated that the general gross anatomy of the ear of the normal adult human is well known. A parallel statement could be made for the speaking mechanism. However, there are areas of vagueness and uncertainty which require additional investigation. Some of these come into sharp focus only when more detailed anatomical information is needed to assist with the resolution of a question concerning function. An example was the controversy during the late 1950's and early 1960's concerning the so-called neurochronaxic theory of phonation, whose advocates claimed that the fine structure of the vocalis muscle made possible the type of active vibratory vocal fold action which their theory asserted. Anatomical studies have aided in resolving this question. Another example is the recently developed interest in muscle afferent systems and their relation to motor control—a development that has many important applications to speech and voice functions and has already given rise to anatomical studies seeking to determine the distribution of muscle spindles within such structures as the tongue and the intrinsic muscles of the larynx.

In summary, while the general gross anatomy of the structures involved in speech production is well understood, there are a number of gaps and areas of uncertainty with respect to fine details. This is especially true with respect to the fine structure of neuromuscular systems which may be important in relationship to speech production and its control.

2. Physiology of Speech Production.

a. Speech respiration. Although the expiratory pressures and the air flow required for speech constitute the basic energy source for all speech and voice production and are thus of the most fundamental importance in an understanding of speech production, there has been relatively little study of the dynamics of respiratory function specifically associated with speech and voice production. Since respiration is one of the vital functions of the human organism, its basic physiology is, of course, an important subject for investigation quite apart from its importance to speech, and there is a substantial literature on nonspeech respiration. Information concerning respiratory function in speech and voice production is, however, much more sparse. A great deal of what appears in textbook discussions of speech respiration is either inference from the literature in nonspeech respiratory physiology, interpretation of empirical and nonquantitative observations of voice therapists, singing teacher, etc., or speculation based on logical deductions concerning the *probable* requirements for speech production. To the extent that such inferences and speculations have not been tested by systematic research, they must be regarded as unverified hypotheses, at best. As previously indicated, the amount of controlled systematic research in this area is meager.

One of the problems that has doubtless limited the accumulation of information concerning the dynamics of speech respiration has been the lack of suitable instrumentation. Space does not permit a detailed consideration of these problems of research technique. In general, they arise from the fact that speech is a rapidly varying dynamic activity which, moreover, is easily modified and disrupted by instrumental intervention. Thus, for example, devices such as the body plethysmograph or the recording respirometer which serve very well for recording relatively slowly varying changes in lung volume are incapable of acting with sufficient speed to follow the rapid variations that are significant to an understanding of the dynamics of speech respiration. An example of the problem of instrumental interference is the fact that most devices for the measurement of a respiratory airflow require the use of some type of face mask which can interfere with speech processes in a number of ways, such as, inhibition of articulatory movements, changing the acoustic characteristics of speech, and modifying the load into which the respiratory system works during speech and voice production.

Recent technological developments indicate that at least some of the previously mentioned instrumental problems may be solved, or at least minimized in the near future. For example, a technique for measuring the transthoracic electrical impedance has been developed which appears to provide reliable data on lung volume under a variety of conditions. Such a system should be much less limited by speed of response than were the older systems of respirometric measurement. Other examples could also be cited.

During the past ten years there have been renewed attempts to utilize electromyographic techniques for the precise description of respiratory muscle function during speech. Despite the technical difficulties in applying electromyography to a region in which the muscular structure characteristically consists of several layers of thin and overlapping muscle sheaths, it has been possible to show that certain electrode locations yield records which provide information on activity that appears to be consistently related to speech utterance. For example, data thus obtained have yielded information concerning the variation in musculature contraction associated with different lung volume levels during speech.

A number of studies have provided data concerning the pulmonary capacity requirements for speech including such data as the tidal air required for speech utterance, the extent to which expiratory reserve is utilized during speech utterances, etc. In general these data are in reasonably good agreement in demonstrating that speech does not tax the capacity of the respiratory system very severely. In fact, a reasonable inference from these data would be that normal pulmonary function could be rather substantially reduced without seriously interfering with speech production.

A beginning has been made in quantitative observation of the expiratory pressures and air flow variations that accompany varying conditions of phonation. In general these observations have been restricted to prolonged phonation and have been made on a relatively small number of subjects. Despite such limitations these data provide useful information concerning the demands which normal speech production imposes on the respiratory mechanism.

An important question concerning the physiology of speech respiration relates to the manner in which the expiratory pressures and air flow variations that are required for speech utterance are controlled. In general, this question concerns the extent to which such control is directly exerted by the muscles which govern the volume of the thoracic cage as compared to the control which may be exercised by laryngeal and supralaryngeal valving of the respiratory airway. Early work by R. H. Stetson advanced the hypothesis that control of speech respiration was primarily a matter of direct control of thoracic cage volume and suggested several types of muscle actions. One type of muscle action, labeled the chest pulse, was presumed to be due to short, discrete contractions of the intercostal muscles and was further thought to be fundamental to the entire organization of speech utterances into syllable units. Recent work, including electromyographic study of respiratory muscle function, has raised serious questions concerning the Stetson hypothesis, and more recently developed data suggest that the process is more complex than Stetson supposed. One study has shown positive correlation between variation in subglottic expiratory pressures and subjective effort during phonation, thus suggesting the importance of direct control by expiratory muscles. Also electromyographic data have shown that variation in the phonetic stress of syllables may be related to the magnitude of muscular contraction. On the other hand, electromyographic data have failed to show a one-to-one correspondence between discrete muscle activity and a separation of speech flow into syllables, as proposed by the Stetson hypothesis. At the other extreme investigators have suggested that the respiraory system acts like a constant volume velocity generator, with the actual variations in expiratory pressures and flows being controlled entirely by glottal and superglottal valving. Currently available information is not sufficient to bring about a resolution of these divergent views, but it seems likely that either one is an oversimplification and that the correct view is intermediate between these extremes.

b. Physiology of phonation. Beginning about thirty years ago the study of the phonatory function of the vocal folds was aided very materially by the development of high speed motion picture laryngoscopy. This technique, which has enabled investigators to make both qualitative and quantitative observations of vocal fold function during voice production, has probably contributed more than any other to our current knowledge of this subject. It is still utilized extensively for the study of both normal function and for the study of function in various pathological laryngeal states.

Laryngoscopic procedures are necessarily restricted, of course, to a view of the superior aspect of the laryngeal structures as seen from above and they can only be utilized under restricted phonation conditions during which the oral-pharyngeal airway remains quite open. However, the only other procedures which have provided for a direct view of the larynx during phonation have been those of tomography, also called laminagraphy. A relatively recently devised variation of laminagraphy provides for a stroboscopically controlled view of the frontal cross-section of the larynx during phonation which permits the vocal fold motion to be viewed as though stopped during any particular phase of its cycle. This technique appears promising because it should provide a view of the vocal fold motion during phonation which has not heretofore been available. However, it is quite new and has had relatively limited use to date.

Other techniques for observation of laryngeal function have included: transillumination procedures, sometimes called glottography; laryngograms made with radiopaque material; study of both static and dynamic mechanical models; and study of the intrinsic laryngeal muscle function by means of needle electrode electromyography. Inferences concerning laryngeal function have also resulted from acoustical studies of the vocal output, acoustical data having been utilized to infer the nature of laryngeal variations that would be required to produce particular acoustical characteristics. For example, studies of the aperiodicity of the voice fundamental, as revealed by acoustical wave forms, have been used as a basis for inference concerning the amount of aperiodicity to be expected in laryngeal vibratory motion in both normal and diseased larynges.

A number of investigators have recently been exploring the possibility of adapting the technique of fiberoptics to the development of a device for direct observation of laryngeal function. If such a device can be successfully developed, it should have advantages over currently available laryngoscopic procedures. However, this work is in a relatively early stage and cannot adequately be evaluated at this time.

Despite the previously noted limitations of research technique, the information currently available on laryngeal function during phonation is sufficient to provide a reasonably good qualitative description of the nature of vocal fold vibration and the manner in which it varies with changes in vocal pitch and intensity. Still needed are data that will yield a more precise, quantitative description. The general form of the opening and closing motion of the vocal folds during phonatory vibration has been described for a variety of phonatory conditions, and there has been some attempt to quantify the nature of the vibratory motion in terms of the time function of the varying glottal width or the time function of the varying glottal area during vibration. For example some investigators have employed quantitative indices, such as the OQ (open quotient) and SQ (speed quotient), to relate the timing of opening and closing phases of vibratory motion to changes in pitch and intensity. A beginning has also been made toward studying the relationship between the spectral characteristics of the acoustic volume velocity generated by the vocal fold vibration and the form of the opening-closing movement; e.g., it has been shown that a reasonable prediction of the volume velocity wave form and its spectrum can be calculated from information concerning (1) the area function and (2) the subglottic pressure. However, these relationships have not been applied extensively to the accumulation of information relating variations in area functions to the associated variations in acoustic spectra for different phonatory conditions. Thus, our knowledge of these relationships is still relatively meager. An additional procedure designated by the term *inverse filtering* has also been used in several laboratories to deduce the nature of the glottal wave form and to infer variations in glottal vibratory motion. In principle this procedure involves processing the output acoustic signal by means of an electrical circuit whose transfer function is the inverse of the filtering action of the supraglottal vocal cavity system. The output of such a circuit should be the wave form due to the glottal vibration. The procedure requires some assumptions which have not yet been adequately evaluated and involves some technical problems, but it appears to have promise as a research procedure for studying the physiology of phonation.

By means of indirect laryngoscopy some data have been obtained concerning the quantitative relationship between vocal fold length and vocal pitch. Corresponding data relating vocal pitch to cross-sectional thickness of the vocal folds have been obtained by means of tomographic procedures. However, these data have been obtained on relatively small numbers of normal subjects and for a relatively small sample of discretely located pitches distributed throughout the vocal pitch range. Consequently, although the data provide information concerning teneral relations, they do not provide an adequate basis for definitive statements concerning the physiologic control of vocal pitch.

Despite their deficiencies, the current data concerning laryngeal function appear to be sufficient to enable a choice to be made between the two conflicting theories of phonation which were the subject of controversy during the late 1950's and early 1960's. Quite clearly the data favor the view that has been characterized by the term, *myoelastic theory, as compared*, to the view of *neurochronaxic theory*. However, currently available data make it possible to state only the broad outlines of a myoelastic theory, and much remains to be learned before a complete, comprehensive theory of the physiology of phonation will become possible.

In addition to that research on laryngeal function which is directly concerned with the generation of voice and the control of phonation, a substantial beginning has been made in studying some of the details of the neuromuscular physiology of the intrinsic laryngeal muscles. The dog, the monkey, and the cat have been the most frequently selected experimental animals. Measurements have been made of the reflex contraction of the cricothyroid and thyro-aytenoid muscles in response to electrical stimulation of the efferent nerves. Measurements have included contraction time, relaxation time, tetanus: twitch ration, fusion frequency and muscle chronaxie. Investigations utilizing electrical stimulation procedures have also been made of the cortical control areas associated with the contraction of intrinsic laryngeal muscles. In general, the intrinsic laryngeal muscles have been found to be fast acting, their contraction speeds approaching those of the extraocular muscles.

The intrinsic laryngeal muscles have also been found to have unusually high metabolic consumption and to be similar in this characteristic, also, to the extraocular muscles. Work of this nature has significant clinical application, e.g., for understanding laryngeal paralyses, the nature of laryngeal growths, et cetera, in addition to the potential contribution of such information to the eventual development of a comprehensive physiological theory of phonation.

Precise basic information on the intrinsic laryngeal muscles requires an acquisition of more basic neurophysiologic data on the recurrent and superior laryngeal nerve topography. These nerves are concerned with the vital function of closure and of opening, as well as functioning alternately and synchronously with respiration and deglutition. The complexities are only magnified by our lack of information in basic neurochemistry and biochemistry of the intrinsic and extrinsic muscles.

c. Pharyngeal-oral-nasal system. The crucial importance for speech production of the vocal cavity system, consisting of the pharynx, oral cavity, and nasal cavity, is probably self-evident. Nevertheless it is perhaps appropriate to emphasize the fact that the phonetic characteristics of speech which enable a listener to differentiate among speech sounds, syllables, words, *et cetera,* are primarily determined by the activity of the articulating mechanism, including the modifications of vocal cavity resonances that are necessary for the formation of different vowel sounds.

Until relatively recently research on speech articulation was significantly handicapped by lack of adequate instrumental techniques for observing many of the details of the relevant movements. For example, although X-ray procedures have long been used for studying the movements and positions of the tongue, jaw, lips, and soft palate during speech production, throughout most of the history of such research investigators had to be content with single exposure X-ray photographs requiring relatively long exposure times. The only speech which could be studied by such means was artificially prolonged productions of isolated, detached speech sounds taken out of the context of dynamic speech flow. Only in recent years, since the refinement of electronic image intensifiers, has it become possible to utilize X-ray techniques for studying the dynamic characteristics of speech articulation. Thus, until recently the information from X-ray studies of speech articulation was more static than dynamic. Similar comments could be made concerning other techniques, e.g., palatography. Despite the relative crudeness of these procedures and their inherent limitations, however, a considerable amount was learned about the shaping of the vocal cavities for the production of various vowel sounds and about the movements and articulatory contacts of the tongue and other structures during the generation of consonant phonemes.

Recent refinement in instrumental procedures, including the development of cineradiography, refinements in electromyographic technique, and development of miniature strain gage transducers for the measurements of articulating contact pressures and displacement have now provided the researcher with a substantially improved potential for studying the dynamics of speech articulation. Because much of this technological development has been so recent, there has been little opportunity to apply these new techniques to research concerned with speech. However, such efforts are going forward in a number of laboratories. Recent work has quite clearly established that much of the earlier information developed by means of cruder techniques which were limited to the study of detached sounds provided a somewhat distorted view of the speech articulation processes. It now appears that the unnaturally prolonged, isolated sounds represent primarily idealized speech sound articulations which are only approximated in actual speech. The movements which occur during the rapid flow of continuous speech appear to be far more complex and much more variable than would be suggested by the earlier data.

It also appears likely as a result of recent work that the conceptual models of speech production processes that most investigators had previously assumed are in need of substantial revision in order to take account of new information concerning speech articulation. Until recently the most prevalent view of speech production assumed that the dynamic flow of speech could be divided into time segments, each of which corresponded to a discreet linguistic unit which might be termed a speech sound, phone, or, in appropriate context, a phoneme. Although for some time data have been accumulating indicating that movements associated with different speech sound units overlap in time and, thus, cannot be considered discreet and independent, until relatively recently it had been thought that such overlapping and blending of movements, often signified by the term coarticulation, could be relatively easily accounted for in terms of mechanical factors inherent in the peripheral structures such as inertia of the articulatory structures which limit the rate of their movement so that very precise movements and positions cannot be realized at the speed required by rapid connected speech. Such an explanation is relatively simple and does not rule out the view that the underlying structure of speech is a linear sequence, or string, of more or less independent speech sound units having a simple one-to-one relation to articulatory events. In this view the overlapping or blending which occurs in rapid connected speech is thought to be related only to the limited rate at which the peripheral mechanism can execute discrete events. However, the most recent research on coarticulation has tended to cast doubt on this explanation. It now appears probable that overlapping movements of the articulators (i.e. movements related to two or more speech sounds) are "programmed" in the central nervous system in the sense that they are represented in the neural events that cause the muscles to contract. If this proves to be correct a rather radical revision of the conceptual models of speech production will be required. Space does not permit a comprehensive review and discussion of the work on physiological phonetics. It is to be noted, however, that not only is this work highly significant for the development of articulatory theory, it is crucially important also because of implications concerning the rationale for rehabilitative procedures for individuals having articulatory speech defects. Additional discussion on this point will be included in the following section having to do with research needs.

As a result of the concentrated interest of a number of specialists concerned with rehabilitation of individuals with clefts of the palate, the articulatory functioning of the velopharyngeal valving mechanism has probably been more studied than any other aspect of speech articulatory activity. Much of the work in which cineradiographic procedures have been applied to the study of speech has been carried out by investigators from these specialty groups having a particular interest in cleft palate. Thus the functioning of the velopharyngeal mechanism in both normal subjects and subjects with various types of palatal defects has been extensively studied. Variations in palatal and pharyngeal action and the relationship of these variations to the significant variables of connected speech have been quite thoroughly explored.

3. Acoustic Characteristics of Speech. Research concerning the characteristics and properties of the acoustical signal that constitutes level 3 of the speech chain diagram shown in Figure 5-1 has a long history. The substantial literature concerning the acoustics of speech that has been accumulated represents the contributions of investigators from a diversity of specialized scientific interests, ranging from communication engineers, whose work is motivated by the very practical goal of improving communication systems, to psychologists, linguists, and phoneticians, whose primary interest is in speech and language as a fundamental human attribute. A great deal of recent interest has been generated by those interested in problems of communication between men and machines. Another specialized interest in the acoustics of speech has developed recently among a group of researchers in psychiatry, who have been seeking to discover significant relationships between pathological personality changes and abnormal voice and speech characteristics.

By comparison to research in speech and voice physiology, investigation of the acoustical characteristics of speech has benefited from the availability of reasonably adequate observational tools. Doubtless this greater availability of relatively precise research techniques accounts in substantial part for the fact that, until relatively recently, a larger proportion of research effort was devoted to the study of the acoustical characteristics of speech than to the study of speech physiology. Even so, much of the early research was severely limited by the inadequacies of available analysis and measurement procedures. The acoustic wave forms of speech are among the most complex of acoustical signals, both from the standpoint of spectral complexity and from the standpoint of rapid and complex variation in time. Thus, until the sound spectrograph developed by the Bell Telephone Laboratories became generally available, about 1950, and until other techniques for processing speech wave forms by means of computers became available at a still later date, data concerning the acoustic characteristics of speech accumulated rather slowly. Moreover, the earlier analysis procedures were not capable of providing good information about the dynamic characteristics of signal variations in time. Consequently, much of the information concerning speech acoustics was limited to description of long-time-average characteristics, or to the characteristics of isolated, detached speech sounds, or was based on highly schematized and simplified utterances. Thus many of the dynamic characteristics of speech were obscured.

This situation was very greatly alleviated by the development of the sound spectrograph, previously mentioned, and during the period of the 1950's there was a rapid accumulation of information concerning the spectral distribution of speech sounds. The sound spectrograph made it possible to accumulate data at a much greater rate than was previously possible, and to obtain data on the characteristics of continuous speech utterance which had previously been difficult to study. As a result, it quickly became evident during the 1950's that the relationships between acoustic characteristics of the speech signal and the perception of speech sounds as distinctive linguistic components was by no means as simple as had previously been assumed by most investigators. Almost from the beginning of acoustical research in speech one of the primary goals has been to describe the specific acoustical properties which function as cues for the significant phonetic discriminations which listeners must make among the consonant and vowel elements of a language. Underlying most of the research in speech acoustics, as well as the research in speech physiology, has been the previously noted assumption that speech is, in fact, segmentable into discreet consonant and vowel segments which are sufficiently independent to be considered to constitute fundamental units of speech utterance and which can, therefore, be meaningfully identified and described. One of the most significant conclusions to be drawn from the substantial accumulation of information concerning the acoustical characteristics of speech which occurred during the 1950's is, perhaps, that this view of speech as a linear sequence of essentially independent and non-overlapping segments is not consistent with the variability and complexity of the speech signal. The implications of this general conclusion have only very recently begun to have an impact on students of speech generally. As a result a great deal of attention is currently being given to the development of conceptual models of the speech process which are more consistent with data derived from both acoustic analysis and physiological research.

Two additional developments within the recent history of experimental research on speech have contributed importantly to our understanding of the acoustical nature of the speech signal. The first of these has been the development of a reasonably comprehensive mathematical theory relating the acoustical characteristics of speech to the properties of the human speech producing mechanism. The second development has been the refinement and elaboration of investigations of the acoustical nature of speech by means of speech synthesis procedures.

Of the several people who have made important contributions to the development of the acoustic theory of speech the names of H. K. Dunn and C. G. M. Fant probably most deserve to be singled out for special mention. Dunn's very important paper of 1950 (The Calculation of Vowel Resonances, and an Electrical Vocal Tract, JASA, 22: 740-753, 1950) was particularly significant as the first relatively successful attempt to develop a mathematical theory based on the analogy of the vocal tract system on an electrical transmission line and to apply such a theory to real cases. Despite a number of simplifying assumptions Dunn was able to show that such a theory could predict the spectral characteristics of vowels from information concerning vocal cavity dimensions with considerable accuracy, and the foundation was thus established for refinements of acoustic theory which have been developed subsequently. The major portion of Fant's important 1960 book (*Acoustic Theory of Speech Production,* The Hague: Mouton and Co., 1960) is a very extensive elaboration of the network theory ideas proposed by Dunn. In addition to its significant theoretical contributions the book summarizes a great deal of empirical work that was carried out in the Stockholm laboratories directed by Fant. Although the theory is still not complete, and it continues to be elaborated and refined, its importance as the basis of our present day understanding of the acoustic nature of speech cannot be overemphasized. Moreover, it constitutes the foundation for nearly all of the work in speech synthesis which comprises such an important part of the current research on speech acoustics.

Work on the electrical-acoustical synthesis of speech has followed two main lines. One of these may be traced primarily from the pioneering work of Dudley in the 1930's. (Remaking Speech, Journal of the Acoustical Society of America, 11: 169-177, 1939.) Although his work had a primary purpose concerned with the improvement of communication systems, and is thus of more direct interest to communication engineers than to other students of speech, it has, nevertheless, contributed significant data of general importance with respect to the acoustic nature of the speech signal. The second type of speech synthesis research has been particularly important because it has provided the means for relatively direct manipulation of the various parameters of the acoustic spectrum which may be important in the identification and discrimination of the phonetic characteristics of speech, or, alternatively, for manipulation of the parameters thought to be significant in the generation of speech signals. The latter parameters are usually, at least by analogy, relatable to physiological characteristics of the speech producing mechanism.

Thus speech synthesis has provided a particularly useful functional test of our knowledge concerning the significance of particular acoustical variables, and of acoustical generating parameters. This work has now reached a state where reasonably intelligible speech consisting of complex dynamic speech utterance can be generated. In the process a great deal has been learned about the acoustical characteristics and acoustical variability of many types of speech utterances. The work on speech synthesis has contributed valuable information and insight into the variations of the acoustical signal that have been characterized as interphonemic transitions and in general has contributed a great deal to our present understanding of the interdependence of adjacent phonetic units.

Among the most recent developments in speech synthesis research are the use of computers to provide programmed control of dynamic speech synthesizers which makes possible the continuous manipulation of speech production parameters in time. Computers have also been used to simulate the speech production processes.

Finally, it should be pointed out that the development of theory relating the acoustic characteristics of speech to physiological processes of speech production has drawn the work in speech physiology and research on the acoustic characteristics of speech closer and closer together. The relatively ready access of the acoustic signal for dynamic analysis in time as compared to the laboriousness required for relevant observations concerning speech production processes has resulted in experiments in which the acoustic data have been used to provide the basis for inferences concerning physiological variables. In principle at least, valid physiological inferences from acoustical data should be possible. The current acoustic theory of speech production is probably not sufficient to provide more than a limited basis for such deductions, and the conclusions reached must be therefore limited to statements of general and not precisely quantified relationships. However, the fact that investigators feel confident in drawing such inferences is indicative of the very substantial advances in theory that have been made in recent years.

4. Speech Perception. As part of our fund of knowledge concerning human communcation, information specifically related to the perception of speech is significant for two somewhat different reasons. It is important within the context of the auditory processes discussed in Chapter 3 because speech constitutes one of the most important types of auditory signals to which the human listener must be able to respond. As explained there, a very important measure of the degree of handicap suffered by a person with an auditory deficit is the extent to which his ability to hear speech is decreased. Within the context of the present chapter and its discussion of the processes of speech production a consideration of speech perception is important because the speaker must be able to monitor his own speech production processes in order to control and manage his speech output.

As is shown in Figure 5-2 it is generally assumed that at least two sensory feedback channels are utilized by the speaker for these monitoring processes. One of these is the auditory channel. The speaker hears his own acoustic output as it is transmitted to the peripheral auditory mechanism by the vibrations created in the air and also by the vibrations transmitted through the body tissues of his head and facial structures. Because the latter acoustic pathway has somewhat different transmission characteristics than the air pathway around the speaker's head, the acoustic cues which enable a speaker to perceive his own speech output are somewhat different than those which stimulate the auditory mechanism of an outside listener. The nature and extent of these differences will doubtless vary with the particular acoustic environment which surrounds the speaker, including such factors as the noise level, the reverberation characteristics of the room, etc. At the present time, however, we have only meager data concerning the differences in transmission characteristics between these two pathways. Technical difficulties have made measurements of the tissue conducted vibration quite uncertain and such data as are available are in some disagreement.

There has been a considerable amount of experimental study of the effects of varying the conditions under which a speaker hears himself. In order to vary the conditions of self-hearing much of this experimental work has been done with a microphone-amplifier-earphone system in which the major part of the auditory signal conducted to the speaker's own ears is by means of earphones. Some interesting and dramatic effects have been demonstrated. One of the most dramatic is the disruptive result of introducing a delay in the auditory feedback pathway. There appear to be large individual differences in the extent to which speech output deteriorates under conditions of delayed auditory feedback. Some speakers find it nearly impossible to continue to talk, or to read aloud. A small number at the other extreme find it possible to continue to speak or read with little sign of disruption of the normal speech patterns. Because the outstanding characteristic of the speech deterioration experienced under conditions of delayed auditory feedback is a pronounced disruption in the normal fluency of utterance, such speech has had at least a superficial resemblance to the speech of stutterers, and has been thought by some to be a method of artificially inducing stuttering. Among experts on stuttered speech, however, there now seems to be general agreement that the resemblance is essentially superficial and that the mechanisms underlying the two phenomena have very little in common.

The effects of varying the conditions of delayed feedback have been extensively investigated including such variables as the level of the feedback signal at the listener's ears, varying the amount of time delay, and varying the spectral characteristics of the feedback signal. The characteristics of the speech disruptions have also been described in considerable detail.

Of course, one of the problems in relating such data to normal speech production is that the pathway that is interfered with is only one of several feedback channels. Moreover, the conditions under which people hear their own speech by means of earphones are not typical speaking conditions. Nevertheless, this information can be useful in helping us understand the speech monitoring processes required for normal speech production. Both the information concerning the varying effects of different delay times and the nature of the errors and disruptions of fluency which occur under delay would appear to be important information that needs to be considered in developing a better understanding of the feedback control system that is operative in speech production.

One of the important outcomes of research on speech perception in the period since about 1950 has been the accumulation of a substantial body of data which demonstrates that much of the information by means of which we discriminate and identify the phonetic units of speech is carried by the time varying portions of the signal which have frequently been thought to be transitional in character and incidental, perhaps even trivial, rather than central in importance. For some types of consonant sounds, at least, those time segments of the signal which have been typically associated with the specific articulatory features usually thought to characterize the sound do not seem to carry much significant information which enables the speaker to identify the particular phonemes. The point has previously been made that both physiological research and research on the acoustical signal have indicated that continuously flowing speech is a very complex phenomenon which cannot easily be segmented into discreet and non-overlapping units. Data on speech perception seem to be consistent with this view. Current information makes it relatively clear that for some sounds and sound combinations, at least, the same time segment in the continuous speech flow may carry information concerning more than one speech sound. All of this raises substantial theoretical issues concerning the nature of speech perception and the fundamental units which are utilized in the production and control of continuous speech utterance. It is probably obvious that closely involved with these theoretical issues are important implications concerning the acquisition of speech and language by young children and the rehabilitative procedures which may be most appropriately used in modifying speech behavior, etc.

An additional important area of research concerned with speech perception is the significance of the tactile and kinesthetic feedback channels. Data on these questions are very meager. It is very difficult to isolate the effect of the tactile and kinesthetic feedback sensory systems. The fact that some persons with hearing loss are able to maintain good speech production for long periods of time appears to provide convincing evidence that these channels can, to a degree at least, be substituted for the auditory channel when the necessity presents itself. Additional evidence of the utilization of the tactile and kinesthetic channels is provided by the learning of speech by deaf individuals. However, such information does not give us much insight concerning how the tactile and kinesthetic feedback channels are actually used by normal speakers with intact auditory systems. A limited amount of work has attempted to study speech under conditions in which the tactile and kinesthetic channels have been partially blocked by application of anesthetics. Other work of a basic nature has been started which is seeking fundamental information concerning the tactile and kinesthetic sensitivity of the oral area. For example, there have been investigations of the two point tactile discrimination threshold in the region of the tongue, and experiments on oral stereognosis have investigated the extent to which the oral structures can differentiate by means of touch among objects having different geometric shapes. Such investigations should eventually provide us with much better information concerning the tactile sensitivity of the articulatory structures. However, the relation of such information to an understanding of the functioning of tactile and kinesthetic feedback channels during the control of speech production is not immediately apparent.

5. Theoretical Developments. Until relatively recently the total amount of scientific effort devoted to the development of systematic theory concerned with speech production was a relatively small proportion of the total research effort in this field. In part this was doubtless because investigators found more than enough to do in attempting to develop more complete and more precise descriptive data concerning the mechanism and processes of speech production, without being overly concerned with theoretical issues. In part, it may have been because, until the accumulation of data reaches some critical stage, one has little to deal with in attempting to devise and evaluate conceptual models of a complex process such as speech production.

In recent years, particularly since about 1960, there has been a drastic change in the amount of effort devoted to the development of theoretical models of the speech production processes. As previously mentioned, beginning in the late 1940's it had become increasingly apparent that speech is a highly variable and extremely complex process. Consequently, the relatively simple set of assumptions that had been thought to constitute a sufficient theoretical framework for the descriptive research that prevailed up to that time, was shown to be inadequate to accommodate the data that were emerging from the laboratories. Moreover, recent years have seen an increasing concern with the development of conceptual models in the biological and behavioral sciences generally. In any event the 1960's have seen a marked acceleration of theoretical publications and discussions. The 1960 book by C. G. Fant entitled *The Acoustic Theory of Speech Production* has already been mentioned. Other publications that have attempted to deal with theoretical issues include several papers by Franklin S. Cooper and Alfred M. Liberman of the Haskins Laboratories,[1] two monographs published in 1966 by Gordon E. Peterson and June E. Shoup,[2] a 1967 paper by William Henke,[3] and a substantial 1968 monograph by Martin Rothenberg.[4] In addition to these publications in English, the extensive 1965 monograph of the Russian investigators, V. A. Kozhevnikov and L. A. Chistovich,[5] should be mentioned.

None of the conceptual models thus far proposed is to be regarded as a comprehensive theory capable of organizing all the available data or providing an explanatory framework for all speech production phenomena. Quite the contrary. Most of the models that have been proposed have been relatively partial, or fragmentary, concerned with the organization and explanation of relatively restricted sets of data, or with relationships stated in relatively gross and approximate terms. Nevertheless, this attention to modeling has made an important contribution in suggesting hypotheses for research, bringing significant research issues into focus, and providing a better means of assessing the current status of knowledge than would otherwise be possible. As a result of this activity several general issues have come to the fore. As previously indicated, one of these is the issue concerning the appropriate segmental unit for analytical study of continuous speech flow. Increasingly, data on both speech physiology and speech acoustics have been accumulating which can not be explained in relation to the assumption that speech consists of a linear string of independent units, i.e. speech sounds or phones. An alternative and somewhat modified view has assumed (1) that speech can be analyzed into a series of time segments by reference to a set of idealized vowel and consonant articulations which can be specified by independent and unvariant characteristics, and (2) that speech as actually produced departs from this idealized utterance because the substantial inertia of the articulatory and other speech structures prevent them from executing precisely the very rapid movement of continuous speech. Thus, the actual movements show variability and considerable overlap. However, this view has also been shown to be inadequate to explain the available physiological and acoustical data. The models so far advanced have made several suggestions concerning the appropriate unit for analysis of speech production, including the Russian view that speech production can not be validly analyzed as a string of speech sounds, but must be considered to be composed of larger units, e.g. syllables. An alternate view that has been advanced by a number of investigators which suggests that a speech utterance may exist as a sequence of phonemes at some high level in the central nervous system, e.g., the cortex; however, this input of phoneme segments is encoded into a program of neural events and the articulatory program is executed peripherally as a set of slowly varying speech production attributes or parameters, two or more of which may be changing simultaneously in a processing system consisting of several parallel channels. In this view each phoneme is characterized by critical values of certain attributes in the total set and a phoneme is generated at the peripheral articulatory level whenever the appropriate critical values occur conjointly. A third view, somewhat similar to the first, suggests that speech may be broken down into a system of automatisms without specifying necessarily that these have a particular sound combination dimensionality, such as that of the syllable.

At the present time it is simply not possible to evaluate with any adequacy the relative merits of the different views. An additional question that has been brought into focus by a number of the theoretical models is the question of the basic control mechanisms which govern the relationships between neural events and peripheral muscular movements. As an example, the nature and function of the gamma efferent system in controlling the movements of speech articulation has become increasingly important. The question as to whether the gamma efferent system is capable of acting as a servo system to control muscular contraction, irrespective of the previous state of the muscle, and independent of the load imposed on the muscular movements, has become a significant theoretical issue in the conceptual models of speech production behavior.

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[1] Cooper, Franklin S., "Describing the Speech Process in Motor Command Terms," *Haskins Laboratory Status Report on Speech Research*, SR-5/6 (1966), 2.1-2.27.

[2] Peterson, G. E. and Shoup, J. E., "A Physiological Theory of Phonetics," *Journal of Speech and Hearing Research*, 9, 5-67, (1966).

[3] Henke, William, "Preliminaries to Speech Synthesis Based on an Articulatory Model," *Proceedings, 1967 Conference on Speech Communication and Processing*, Paper #C-6, 170-177. See also Henke, William, *Dynamic Articulatory, Model of Speech Production Using Computer Simulation*, Ph.D. Thesis, Massachusetts Institute of Technology, (1966) University Microfilms.

[4] Rothenberg, Martin, "The Breath-Stream Dynamics of Simple-Released Plosive Production," *Bibliotheca Phonetica* No. 6., Verlag S. Karger, Basel (Switzerland) 1968.

[5] Kozhevnikov, V. A. and Chistovich, L. A., *Speech: Articulation and Perception* (Translated from Artikulyatsiya i. Vospriatiye, Moscow-Leningrad, 1965) U.S. Department of Commerce, Joint Publications Research Service, JPRS 30, 543.

As suggested previously, the fundamental question of the appropriate unit is important in relation to theory, in relation to empirical research on clinical problems, and in relation to clinical applications concerned with the treatment of disorders of speech production. An additional theoretical issue concerns the relative roles of auditory cues vs. cues concerned with the physiological events of articulation in relation to speech perception. Some researchers have advocated a view which they have called a *motor theory of speech perception*. The advocates of this theory have cited the variability and complexity of the acoustic characteristics of speech as evidence indicating that the perception of speech sounds cannot be adequately explained by reference to invariant characteristics of the auditory signal. As an alternative they have advanced the suggestion that a more simple relationship exists between perceived speech units and the motor events of speech production, and that these motor events may therefore mediate the perception process in some fashion not yet clearly understood. Although a limited amount of data can be cited in support of the latter view, a definitive conclusion, pro or con, with respect to the motor theory is hardly possible at this point in time.

B. *Research Needs.*

1. Anatomical. As indicated previously the gross anatomy of the speech production mechanism has been well investigated. However, there are gaps and uncertainties with respect to certain details and appropriate anatomical studies will continue to be important for the foreseeable future.

One area in which additional information is of particular significance with respect to an understanding of speech and voice is that of the change in structures which are related to growth and development. For example, although the general picture of growth of the larynx is known, the available data are not sufficient to provide a detailed description of growth changes throughout childhood and adolescence, nor of the relationship of such growth changes to significantly associated variables, including general bodily growth, development of sexual maturity during adolescence, or possible endocrine factors, etc. Such information is certainly important for a comprehensive theory of voice production, as well as in understanding the causes and natures of certain types of voice disorders. Likewise, data concerning the growth and development of the facial structures which form the oral, pharyngeal, and nasal passages are not sufficient to provide good normative information. To assess the probable significance of deviations in structures that may be observed among individuals having speech deficits one needs not only good data concerning averages, but also information concerning the range of individual differences to be expected.

Anatomical studies have always needed to keep pace with new developments in physiology, so that they may continue to provide the basic information concerning structure which comprises the essential basis for any physiological explanation. A few examples are as follows. As previously noted, physiological studies of the intrinsic muscles of the larynx have been investigated and various details concerning neuromuscular function, including speed of response, maximum force of contraction, etc., have been described. Most of these studies have necessarily been done with animals. The extent to which valid conclusions concerning humans can be drawn will depend to no small extent on the degree of similarity in detailed structure between human subjects and the experimental animals. Some of these details include size and distribution of muscle fibers, number and distribution of motor end plates of peripheral motor nerves, etc. Another example is the need for much more complete information concerning the distribution of stretch receptors in nearly all of the muscle systems involved in speech production. Such information is probably most critically needed with respect to the muscles of the larynx and the speech articulators, i.e., the tongue, soft palate, lips and jaw muscles. It seems increasingly clear that to understand the important neuromuscular relationships involved in speech production a kind of servosystem control, which many think is provided by the gamma efferent system, will need to be taken into account. Adequate anatomical information concerning the number and distribution of muscle spindles is essential, therefore, to an understanding of vocal articulatory physiology.

The foregoing are simply examples. It is not possible to forecast in detail the need for new information concerning such anatomical details. It is, however, reasonable to suppose that as new understanding concerning neuromuscular activity of the speech production structures and new conceptual models of muscle control are developed, there will be additional needs for supporting anatomical information.

2. Speech Physiology.

a. Respiratory function. As previously indicated, the data on speech respiration are relatively meager. However, new technological advances appear to have minimized, or substantially reduced, some of the difficulties which have thwarted investigators in the past. Hence, it should be possible to extend our knowledge of speech respiration much more rapidly in the future. The beginning which has been made in studying the function of the respiratory muscles during speech by means of electromyographic procedures needs to be extended, both to increase our information concerning which muscles function most importantly and under what conditions, but also to provide information concerning the timing of respiratory muscle activity in relationship to variables of the speech utterance, and in relationship to respiratory variables such as lung volume. The data concerning muscle activity needs to be carefully correlated with information concerning respiratory pressures and flows. Primarily the problem is to learn as completely as possible how the expiratory pressures and the flow of air which is the basic energy source for speech are controlled. Much of the currently available information is of a very general nature. Most of it relates to relatively static states, such as prolonged phonation. What is needed is a thoroughgoing aerodynamic study of the pressures and flow variations accompanying continuous speech which will consider what is happening in all parts of the speech mechanism and which will provide a basis for evaluation of the relative importance of various possible control factors governing the expiratory flow of air for speech. It appears virtually certain that speech respiration must be governed by some combination of (1) direct control of the thoracic volume and (2) control due to the valving which takes place both at the glottis and as a result of articulatory constrictions and occlusions. One of the interesting points, of course, is that such a combination of controls would appear to require a very high degree of fine coordination between disparate neuromuscular systems in which important characteristics such as neural transmission time, vary substantially. At the present time we have such meager data that it is possible to do little more than speculate about the probable nature of this coordination.

b. Laryngeal physiology. The status of knowledge concerning phonatory function, and the status of technology required for the observation of laryngeal activity would appear to indicate that the timing is right for developing our present relatively gross and qualitative understanding of the relationships between vibratory activity in the larynx and the acoustic output of the glottal vibration into a much more precise and quantitative description of these significant relationships. In order to do this, the beginnings of quantitative studies of variables involved in phonation which have so far found their way into the literature must be substantially extended. Descriptive data based on an adequate number of subjects and covering a wide range of conditions of phonation are needed for such variables as (a) subglottic pressures; (b) glottal air flow; (c) effective vibrating lengths of the vocal folds; (d) effective thickness of the vibrating folds; (e) shaping of the laryngeal tube in relation to components of laryngeal resistance (e.g., turbulent versus laminar flow, etc.) As previously indicated, a very small amount of data concerning relationships among these factors is currently available. If we are to develop a comprehensive understanding of the factors affecting phonation, including variations in pitch, intensity, and such tone quality variations as may be attributed to the larynx, a much larger and more complete body of empirical data is needed. Data are also needed which will provide bases for improved understanding of the precise relationships between the wave forms and spectra generated by the laryngeal vibration, on the one hand, and the details of the vibratory motion on the other. Current theory appears to provide the rationale for investigating such relationships and the techniques of high speed motion picture laryngoscopy and inverse filtering appear to provide possible observational approaches. To date these possibilities have not been exploited to any appreciable extent and there is urgent need for experimental work along these lines.

As already suggested, a detailed study of the larynx as an aerodynamic system is needed both for better understanding of phonatory function, *per se,* and also to provide information concerning the coordinated control system required for governing expiration air flow during speech.

Another area of research need with respect to laryngeal structure and function is for more biochemical research on the larynx. Data are available regarding the metabolic action of the intrinsic muscles of the larynx, but knowledge of the cytochemical aspects of the laryngeal epithelium and the neurochemical aspects of the superior or recurrent laryngeal nerves is meager.

c. Articulatory function. As previously indicated, until recently technological limitations restricted the study of articulatory movements to observations based on simplified and stereotyped utterances, often prolonged vowels or monosyllables having very simple structure. Information obtained from such biased and limited sampling of speech activity was necessarily of a very restricted kind with an unavoidable emphasis on static positions rather than dynamic movements. It was impossible to study the dependence of speech articulation upon phonetic context to any satisfactory degree and the general complexity and variability of continuously flowing speech was simply not available for study. Although there are still substantial technological problems, research procedures have been developed which make possible the accumulation of data on the dynamics of speech to a far greater degree than was possible a short time ago.

One such technique is cinefluorography. As previously indicated this procedure has been applied more to the study of the movements of the soft palate than to any other articulatory structures. However, some research concerned with movements of the tongue and the varying shapes of the articulatory cavities have been carried out. Much more needs to be done. In general such work needs to be carefully guided by hypothetical models of the articulatory processes. So far as possible, such data should also be collected by means which will make it possible to relate the movements and shaping of structures as revealed by cineradiographic procedures to varying aerodynamic characteristics and to muscular activity as revealed by such procedures as electromyography.

In very recent years a beginning has been made in the application of electromyographic procedures to the study of articulatory movements. However, except for the lips which are relatively accessible to the application of electrodes without significant interference with speech movements, the application of EMG procedures to speech activities is difficult, both because of possible distortion of the speech movements as a result of the presence of electrodes, connecting wires, etc., and because of the great muscular complexity of such structures as the tongue, for example. Nevertheless, a beginning has been made, and it appears that data which may be usefully related to the generation of phonetically significant variations can be obtained by EMG methods. Among the current problems that need to be solved before electromyographic data can be adequately interpreted is a need for improved understanding of the relationship between the muscular contractions which give rise to an EMG signal and the neural impulses which stimulate the muscle fiber contraction. Some investigators have assumed a relatively simple relationship between the "motor command" as represented by the alpha neural impulse and the EMG record, so that direct inferences concerning the motor command would be possible from electromyographic data. However, reasonable conceptual models attempting to utilize what is known about the gamma efferent system and its relationship to motor control suggest that this relationship may be far from simple and that such direct inferences concerning motor commands may not be warranted. Although the nature of interpretations that may be validly made from electromyographic data will depend upon how this tissue is resolved, the significance of EMG data as basic descriptive information concerning articulation will probably not be diminished.

The importance of aerodynamic studies of the entire speech production process has previously been mentioned. At this point it needs only be said that such studies should certainly include the oral pharyngeal and nasal cavities and the data should be obtained in such a way as to make possible correlation with cineradiographic and electromyographic studies.

The importance of the issue concerning the appropriate analytical unit for describing continuous speech has previously been emphasized, and the theoretical and practical significance of this issue has been stressed. From the standpoint of understanding speech production as a skilled motor performance which can be learned, practiced, and perfected, and which can be disrupted and interfered with as a result of structural changes due to disease or injury, a much better understanding of the nature of the habit system which constitutes our learned motor skills for speech production is needed. Such questions as the following would seem to be relevant. What is the smallest movement pattern that may be thought of as constituting a unitary speech gesture? In the rapid flow of continuous speech, do such speech gestures maintain a discrete and independent unity, or do they become reorganized into larger automatisms which in themselves constitute learned habit patterns? What are the relationships among such habit patterns and the component movements of which they consist? When such habit patterns, or automatisms, are deficient or defective, how can they most effectively be modified, i.e., what aspects of them can be changed without interfering wtih the pattern in some other crucial respect? In general the answers to these questions cannot be derived from currently available data. Studies which will provide the information which can constitute the basis for developing answers to these questions are urgently needed.

3. Acoustical Research. Previous work in the acoustic analysis of speech has provided a considerable amount of data concerning the acoustic characteristics of assumed phonetic units, such as vowels and consonants. Data have also been obtained which give reasonable description of some of the dynamic characteristics of interphonemic sound linking, e.g., the transitional characteristics which occur between the steady-state portions of the speech signal usually associated with the central, or nucleus, portions of vowels and consonants. A sufficient quantity of such acoustic phonetic data have been generated so that it has been possible to develop a reasonably sophisticated acoustic theory of speech relating physiological and acoustical events in the production of speech.

To further the understanding of the fundamental nature of the acoustical signals of speech, the questions which are now most pressing would seem to be those which concern the dynamic character of time variations in the speech signal. Many of these questions can probably best be answered by speech synthesis procedures, rather than the more traditional speech analysis techniques that have been largely utilized in the past. The technology for implementing such speech synthesis studies is, in the main, available in the form of dynamic control (e.g. by programmed computer control) of electronic speech synthesizers or, alternatively, computer simulation of the entire speech synthesis process. In most such work that is currently going on, the acoustical parameters being manipulated relate more closely to the end product, i.e., to the speech signal, than to the speech generating process. In these studies the question as to whether the means by which the parameters are varied are, in fact, directly analogous to the actual processes of speech production is considered secondary. This may be justified, so long as one's concern is limited to processing speech for communication engineering purposes, or for the generation of speech-like stimuli in which the parameters may be varied systematically for some other purpose, such as studies of speech perception. However, to understand more completely how the speech production mechanism functions as an acoustic generator, it is necessary to use techniques which are, in fact as closely analogous as possible to the function presumed to be performed by the speech mechanism. Some work of this kind is also going on. However, this work has only been begun and a great deal of emphasis needs to be placed on speech synthesis studies of all types in the immediate future. These studies give promise of providing us with highly significant information about the dynamic characteristics of speech acoustics and they should be encouraged and supported in every possible way.

4. Speech Perception. To some extent the research needs in the area of speech perception were indicated in the summary of contemporary knowledge in this area. There is a particularly urgent need for information which will provide a better basis for understanding the process of self-listening by means of which an individual controls his own speech production processes. It is probable that the kind of information that can be developed by means of the techniques which have previously been most extensively used has largely been realized and that new techniques will need to be developed before much additional progress can be expected. The perception by a speaker of his own speech activity and output needs to include the study of all channels by means of which such information is fed back and used in the control of speech production processes.

5. Theoretical Developments. Little needs to be said here beyond the obvious point that all interpretation of data and information depends upon the adequacy of the conceptual models by means of which we seek to organize our data and to refine our hypothesis concerning the processes under study. Moreover, the effectiveness of research, the relevance of research questions that are asked, the significance of hypotheses that are tested, etc., is crucially related to the theoretical thinking that underlies the analysis of research questions. In an area of research where the complexities are as great as they are in most facets of speech production the importance of theory development tends to be accentuated. It cannot be too strongly emphasized therefore that a reasonable proportion of researchers' time and energy should be devoted to the elaboration and refinement of the explanatory models of speech production processes. Such work should be encouraged and supported in every possible way.

III. PATHOLOGIES AFFECTING THE SPEECH PRODUCTION SYSTEMS

A. *Status of Contemporary Knowledge.*

1. Respiratory Mechanism. The cumulative amount of systematic research seeking to relate pathological states of the respiratory mechanism to disorders of speech and voice has been relatively meager. Most of the statements contained in the literature which assert causal relationships between respiratory pathologies and speech and voice disorders are statements of opinion based on clinical observations. In general, the critical researches that are needed to verify such opinions have not been attempted. Hence, most such opinions must be viewed as plausible, but untested hypotheses.

The research on normal breathing processes for speech and voice, referred to in a previous section, has demonstrated that ordinary levels of conversational speech constitute no more than a light-to-moderate load on the respiratory mechanisms. Lung capacities are considerably greater than those required for ordinary speech, and the ability to generate respiratory pressures and flows is much larger. Hence, reduced vital capacity, such as may result from removal of one lung or from a disease such as myasthenia gravis, is not likely to be causally related to a speech or voice disorder. Obviously, some minimum lung capacity is required to generate the necessary respiratory pressures and flows needed for adequate speech production, and there are numerous statements in the literature which express the opinion that extreme shallow breathing contributes to vocal inadequacies. In general, however, these statements have not been derived from quantitative data concerning the minimum requirements for adequate speech and voice. Probably, one of the reasons why more such data are not available is that individuals having respiratory involvement which is so serious as to interfere significantly with speech production tend to have general health problems of such serious nature that they usually outweigh the voice disorder that may result.

The clinical observation that speech and voice disorders in certain types of patients, such as cerebral palsy, pseudobulbar palsy, etc., are frequently associated with relatively severely disturbed respiratory function, and that such patients may also show reduced lung capacities, has led a number of writers to conclude that there are causal relationships between reduced lung capacity and speech and voice problems in such cases. On the other hand, such evidence as is available from systematic research suggests that the reduced lung capacities, *per se,* do not constitute a fundamental respiratory problem that interfers with adequate speech production. The problem seems to be more closely related to diffculties in the neuromuscular control of expiratory air flow than to reduced lung capacity.

One of our consultants has provided the following summary statements concerning speech and voice disorders associated with respiratory pathology:

> In a small percentage of persons, respiratory functions may be so impaired that the supply of breath and the ability to control its flow significantly restricts their potential for normal speech. Among those who may display such problems are patients with congenital cerebral palsy, myasthenia gravis, pseudobulbar palsy (bilateral pyramidal tract involvement), amyotrophic lateral sclerosis, Parkinson's disease, and various movement disorders (chorea dystonia).
>
> Even though such deviations from normal may have potential effects on speech and even though it is apparent that there must be some minimal level breath support to sustain adequate speech, data are available which emphasize that such absolute values as measures of vital capacity may not be the true indices of the influence of respiration upon speech. It has been shown that the impairment of oral musculatures in cerebral palsied children cause them to valve their available air stream less efficiently than children of equal vital capacities but without paresis of the articulators.
>
> Adult patients with neurological disease may display speech and voice characteristics possibly related to respiratory impairment. Patients with myasthenia gravis may display a reduction in the excursion of the thoracic cage and only partial descent of the diaphragm during inhalation. Vital capacity may be significantly reduced; and inefficient valving at the glottis, in the oral cavity, and at the velopharyngeal sphincter may result in inefficient use of what breath supply there is.

In summary, our present knowledge of the relationship between speech and voice disorders and pathologies affecting the respiratory mechanisms is largely based on clinical observation and there has been little systematic, quantitative research. Although it is obvious that some minimum volume of breath supply is needed to sustain speech and voice, we do not have adequate quantitative data to specify what are the minimum respiratory capacity requirements for adequate speech production. Data concerning the extent of reduction in respiratory capacities, or the specific character of respiratory dysfunction (e.g., dysfunction in the control of respiratory pressures and flows) that are associated with specific pathological conditions are very meager. The available data on nonspeech respiratory changes associated with various disease states are not readily relatable to speech and voice production, especially since our knowledge of normal speech respiration, and in particular the control of respiratory pressures and flows during speech, is so incomplete.

2. Laryngeal Mechanism. The bulk of present knowledge concerning the etiology, nature, and treatment of voice disorders due to laryngeal pathology has been derived from clinical observation and case reports. Until recently there was little systematic or quantitative research leading to precise description of the nature of voice disorders associated with particular types of laryngeal pathology. Within relatively recent years, especially since 1950, a few researchers have been engaged in applying more precise observational techniques, such as high speed motion picture laryngoscopy, electromyography, acoustic spectrographic procedures, and careful studies of voice aperiodicity to provide more precise description of the nature of vocal problems and vocal symptoms exhibited by individuals with laryngeal pathology. Although such efforts appear to be promising and should yield far more exact information concerning relationships between laryngeal pathology and laryngeal functioning for phonation than is currently available, it is still too early, and the amount of data accumulated is still too meager, to permit a reasonable evaluation of the information based on such research.

Up to the present time there has been little systematic research in which the techniques for studying subglottic pressures, laryngeal air flow, and aerodynamic resistance of the larynx have been applied to the study of patients displaying various types of laryngeal pathology. Thus, we have little exact description of the significant aerodynamic effects which may be significantly related to phonatory dysfunction resulting from various types of laryngeal pathology.

Laryngeal pathologies can be classified in the following categories: (1) injuries and destruction of laryngeal tissue resulting from such factors as vocal abuse, mechanical and chemical irritants, surgery and injury resulting from accidents; (2) diseases and growths, including infections from internal and external sources, paralyses, benign and malignant tumors, etc.; (3) congenital conditions; (4) hormonal deficiencies; (5) degenerative or collagen disorders. The vocal symptom most commonly described as associated with laryngeal pathologies is that of hoarseness, especially if the pathology involves some abnormal growth on or near the vocal folds, or significant laryngeal infection or inflammation. Numerous authors have stressed the importance of persistent hoarseness as a clinical sign which may be the first evidence of significant laryngeal disease.

Laryngeal pathologies related to hormonal deficiency tend to be associated more with abnormalities of vocal pitch than with changes in tonal quality of the voice. However, the voices of adult women suffering from hormonal deficiencies have been described as sounding excessively masculine in both pitch and tone quality. Such descriptions represent subjective impressions, and there has been little systematic, quantitatvie analysis. One of the problems in attempting to assess the causes of certain types of vocal disorders is that some symptoms that are frequently thought to be associated with hormonal deficiencies have also been considered to be the result of emotional and personality disturbances. Conflicting opinions can be found in the literature concerning the relative importance of these two causes in relationship to certain vocal symptoms of pitch and tone quality. Present data appear to be insufficient to allow for adequate evaluation of these conflicting opinions.

The specific diseases and pathological laryngeal states that may be associated with hoarseness in adults are very numerous. Many of the acute diseases in this group have greater significance with respect to the general health of the individual than with respect to any problems of communication which may be associated with them. However, following medical and surgical treatment to assure the person's continued good health there may be a significant communication handicap as a sequel of the medical and surgical treatment. An obvious case is the individual suffering from laryngeal carcinoma of such degree as to require a total radical laryngectomy. The vocal and speech consequence of such surgical procedure is, of course, complete aphonia, together with problems of speech articulation resulting from the fact that the vocal tract is permanently disconnected from the respiratory mechanism.

Such radical treatment is not required for all patients having laryngeal carcinoma. With less extensive surgery good communication can usually be maintained. There has also been progress in the development of alternative surgical procedures, such as the tracheo-pharyngeal speaking tube operation (Asia) which provides a good voice for the patient.

Current literature on voice disorders appears to ascribe an increased importance to the causal factor of vocal abuse both with respect to pathological states thought to be causally related to vocal abuse and with respect to vocal symptoms that may result therefrom. Vocal nodules, or singer's nodes, have long been thought to be caused by vocal abuse. More recently there has been increasing opinion indicating that contact ulcers may also be related to misuse of the vocal mechanism. For example, data have suggested that contact ulcers may result from habitual use of vocal pitch levels which are poorly suited to the individual's laryngeal mechanism.

3. The Pharyngeal-Oral-Nasal System. As stated in the earlier section concerned with normal speech production, the pharyngeal-oral-nasal system has a dual function in the generation of intelligible speech. First, it constitutes a resonant transmission system having frequency selective characteristics which modify the spectral characteristics of the complex tone generated in the larynx and thus give to the various voiced speech sounds the particular properties which enable listeners to identify these sounds as distinctive phonemes of the language. Secondly, the tongue acting in conjunction with the velum, hard palate and teeth, and the lips acting together or in conjunction with the teeth, constrict or obstruct the oral channel. By means of articulatory actions the air stream is modulated and aperiodic noises are generated within the vocal tract. This aperiodic noise generation is a characteristic of the production of many of the consonant sounds. In addition to the above actions which are primarily concerned with the formation of speech sounds, the selective filtering action of the vocal transmission system has a significant effect on the tonal quality of the voice.

The various pathological states and structural defects of this portion of the speech production mechanism which may have adverse effect on the speech output will be discussed under the following headings: cleft lip and palate and velopharyngeal incompetence; abnormalities of dental structures; abnormalities of the tongue.

a. Cleft lip and palate and velopharyngeal incompetence. The complex problem of general health, cosmetic appearance, otologic complications, and speech and voice adequacy of individuals suffering from the congenital defects of cleft lip, cleft palate or combined cleft lip and palate have been the joint concern of a group of specialists which has included plastic surgeons, otolaryngologists, orthodontists and prosthodontists, and speech pathologists. As a result this condition has received extensive study, particularly in the last twenty years. As a consequence a good deal is known concerning the incidence of cleft lip and palate, the distribution of severity of lip and palate defects, the tendency of lip and palate defects to be associated with other congenital defects of the facial region, and the consequence for speech of such abnormalities.

There has also been a considerable amount of study concerning the etiology of cleft lip and palate. Although much remains to be learned, studies of both human and animal subjects have established a strong presumption that in a substantial proportion of cases the cleft condition is genetically determined. It also appears probable, from both human and animal studies, that toxic factors which are effective during pregnancy may in some cases be causally related to such birth defects. A definite conclusion from these studies of toxic factors is that they can only be significant in causing lip and palate defects when they are effective during the critical prenatal period when the lip and palate structures are developing and undergoing midline fusion. In the human this critical time is in the latter part of the first trimester of pregnancy, i.e., between the 10th and 12th weeks following conception. The one toxic factor whose causal signifiance seems to be clearly established is illness of the mother with rubella during this critical time.

As previously stated the relationship between clefts of lip and palate and their speech consequences has been extensively studied and is generally well understood. Consequently, a good deal of the research relating to this type of defect in recent years has been concerned with the evaluation of management procedures. This will be considered in a later section.

Speech and voice defects highly similar to those which characterize cleft palate are associated with a condition which is sometimes characterized by the term velopharyngeal incompetence. Inability to obtain adequate velopharyngeal closure may be due to such varying conditions as a congenitally short palate, paralysis of the palatal muscles, myasthenia gravis, and injuries to the palatal structures. The general principles relating such inadequate functioning of the velopharyngeal mechanism to speech and the principles concerning appropriate management procedures are highly similar to those for individuals having overt clefts.

b. Defects of dental structures. Studies of relationships between dental defects and speech function indicate that malocclusion and misalignment of teeth play a significant relationship to speech articulation. However, the possibilities for compensatory adjustment of the articulatory mechanism seem to be sufficient to overcome at least moderate degrees of dental defects, so that such defects seldom constitute significant disabling factors which prevent the development of normal articulation. Available data indicate that individuals who exhibit moderate degrees of malocclusion and dental misalignment exhibit greater frequency of articulatory errors than do persons with good dentition, especially if the anterior teeth are involved. The data also indicate that the frequency of articulatory errors is positively correlated with the degree of severity of dental effect. Case reports indicate, however, that in individual instances extremely severe dental defects have been compensated by articulatory adjustments to the extent that no significant speech handicap has resulted. For example, malocclusion of the anterior teeth of such severity as to prevent normal closure of the lips must preclude the normal articulation of bilabial stops. Nevertheless, such severe malocclusion has been compensated for to the extent that no audible effect on speech articulation can be noticed. In summary, it would appear that dental abnormalities and defects constitute a complicating factor to the development of normal articulation, but with the exception of the most severe conditions of malocclusion they seldom constitute a disabling factor. Most individuals have the ability to develop compensatory adjustments of articulation sufficient to offset a relatively severe dental defect.

c. Effects of tongue structure and function. There seems to be general agreement that unless deviations in the size of the tongue are very gross, no significant effects on speech should be expected. In some cases, however, severe macroglossia has been found to be associated with articulation problems. Microglossia appears to present less of a problem, and the literature contains several case reports of individuals with congenitally absent tongues who, nevertheless, have developed intelligible speech. One such case has been studied extensively, and the compensatory movements which this individual developed have been rather carefully described. Other case studies indicated that radical surgical removal of large portions of the tongue may result in significant alterations of an individual's articulation, but that the individual will probably not be rendered speechless.

A particular phenomenon relating to tongue function that has been of substantial interest to both dentists and speech pathologists in recent years is that which is known both by the terms *tongue thrust* and *reversed swallow*. Partly because of lack of clear definition and description of the condition designated by these terms, there appears to be relatively little agreement concerning the incidence of these conditions among children, or the relation of these conditions to the development of normal speech articulation. Some of the studies that have attempted to investigate the tongue thrust problem have been criticized for deficiencies in experimental design, particularly on the ground that comparison to adequately selected control groups of normal subjects has been lacking. Thus, the data with respect to tongue thrust appear at this time to be quite inconclusive. The present evidence suggests that these problems of unusual tongue function in infants and small children may be causally related to the development of abnormal dentition. There appears to be less evidence of relationship to the development of abnormal speech.

4. Neurological Disorders Affecting Speech Production.

a. Laryngeal pathologies. Pathologies affecting the central nervous system can generally be expected to have widespread effects involving neuromuscular function, sensory function, and defects of perception as well as direct effects on communication. Such pathological central nervous system conditions will be considered in a later section. The discussion at this point will be concerned with laryngeal paralysis caused by pathology of peripheral nerves. One of our consultants has summarized available information on this topic as follows:

> There is general agreement among laryngologists that most laryngeal paralyses are associated with lower motor neurone lesions rather than with supranuclear lesions. Dolowitz (1964) estimates that central lesions cause only ten per cent of vocal cord paralysis while peripheral lesions account for ninety per cent with most peripheral lesions occurring on the left. The nature of the vocal symptoms is related to the position assumed by the vocal cords which in turn is related to the site and extent of the lesion. Hence, damage to the peripheral nerve supply to the larynx may produce a variety of vocal disturbances.

Greene (*The Voice and Its Disorders*, Philadelphia: J. B. Lippincott, 1964) lists eight types of laryngeal paralyses and corresponding vocal symptoms:

1. *Unilateral Abductor Paralysis*
   Affected cord lies in median position. Voice is hoarse at first but quickly recovers.
2. *Bilateral Abductors Paralysis*
   Both cords lie in median position. Most serious of paralyses. Strong phonation is possible but difficulty in breathing is extreme.
3. *Complete Unilateral Recurrent Paralysis*
   Most common. Adductors and abductors are paralyzed in affected cord but healthy cord develops compensatory movement. At first the voice is hoarse and breathy but gradually reverts to normal.
4. *Complete Bilateral Paralysis*
   Both cords lie in paramedian position. Phonation is impossible. With excessive effort an audible whisper may be produced.
5. *Unilateral Superior Laryngeal Nerve Paralysis*
   Rare. Voice is hoarse and rough. In some cases only slight breathiness and lack of pitch change is evident.
6. *Bilateral Superior Laryngeal Nerve Paralysis*
   Hoarse voice with lowered pitch and lacking in inflection.
7. *Combined Unilateral Paralysis*
   Aphonia initially but gradual recovery of phonation if healthy cord develops adequate compensatory movement.
8. *Combined Bilateral Paralysis*
   Permanent aphonia.

It is difficult to make general statements concerning the vocal symptoms that will be associated with such laryngeal paralyses. The nature of the symptoms and the prognosis for recovery of usable voice depends on a number of variable factors including, according to one authority, (1) types of onset of paralysis, (2) position and muscular tonus of immobilized cord, (3) permanent structural changes within the cord, (4) shape of glottis, (5) level differences between the cords, (6) position of the arytenoid cartilage, (7) type and degree of compensations by unaffected laryngeal structures, (8) patient's emotional reaction to his disability and his individual skill in overcoming it.

b. Peripheral cranial nerve lesions affecting other speech structures. Injuries and disease may also result in paralyses of the tongue muscles, of the soft palate, pharyngeal muscles, faucial pillars, etc. Any or all of these can seriously interfere with normal speech articulation. Particular effects will, of course, depend upon the location, extent and nature of the paralyses. For example, paralyses of the soft palate or the pharyngeal muscles may produce velopharyngeal incompetence which will have the same general effect on speech as would velopharyngeal incompetence resulting from a congenitally short palate.

c. Cerebral palsy. One of the most common types of central nervous system pathologies having significant effects on speech production is the set of congenital neuromuscular disorders subsumed under the generic term, cerebral palsy. Generalizations concerning the relationship between cerebral palsy and speech dysfunction are difficult because of the great variation in neuromuscular symptoms which are included in this category. Not only does the category include several diagnostic types, i.e., spastic paralysis, athetosis, ataxia, rigidity, etc., but within each type there is an extreme range of variation with respect to the regions of the body which may be affected and the severity of the involvement. The situation is further complicated by the fact that individuals with cerebral palsy frequently, though by no means always, suffer from an associated impairment of intellectual functioning.

By the same token, the individual who seeks to do systematic, analytical research with respect to cerebral palsy is confronted with serious difficulties. He can seldom hope to carry out his research on a sample of subjects having sufficient homogeneity of symptoms to permit consistent behavior to be observed. As a consequence most of our present knowledge concerning the speech production problems associated with cerebral palsy is based on clinical observations.

Depending on the portions of the body which are affected by the neuromuscular dysfunction any or all parts of the speech mechanism may be involved. The muscles of the trunk which control both posture and respiratory function are very commonly affected, and individuals with cerebral palsy often show reduced lung function. However, studies of the respiratory function during speech of children with cerebral palsy suggest that their speech problem is one of control of respiratory pressures and air flow, rather than inadequate lung volume. Moreover, the degree to which poor control of air flow is significant seems to be closely related to inefficient functioning of valving mechanisms in the larynx and the articulatory structures. The intrinsic musculature of the larynx may, also, be involved in the neuromuscular dysfunction associated with cerebral palsy so that the action of adduction and abduction of the vocal folds, control of length and stiffness of the vocal folds, etc., may show serious incoordination. The general picture in such instances is one of extremely poor vocal control which may include difficulties in control of pitch, loudness, inflection patterns, etc. Difficulties in the coordination of the adductor-abductor function may range from adductor spasms which produce such extreme glottal closure that phonation cannot be initiated to abductor spasms which present approximation of the folds or which may produce interruption of phonation. Extreme aspirate voice quality is also a commonly noted result.

It is probable that the most significant aspect of the speech problem associated with cerebral palsy is that affecting the articulatory processes. This would appear to be the case because severe articulatory dysfunction has a more pronounced effect on the intelligibility of speech utterance than do phonatory problems associated with laryngeal dysfunction. Thus, as serious as the respiratory and laryngeal problems may be, malfunctioning of the articulatory mechanism is likely to be more handicapping. Moreover, as has previously been noted, the valving function of the articulatory structures plays a very important role in the control of air flow, and this may be seriously affected by neuromuscular dysfunction involving the articulatory mechanism.

Studies of the articulatory errors which may be exhibited in cerebral palsy serve primarily to emphasize the very great range of severity which may be seen, extending from speech which is relatively normal to that which is essentially unintelligible to the average listener.

A research direction which has been attracting recent interest is that which concerns the role of oral sensation and perception in the acquisition of articulatory skills. This has particular relevance for children diagnosed as having cerebral palsy since there is evidence showing that certain of these children have significant deficits in somatic sensory discrimination. Although most of the work has been done on body sensation, e.g., the hands, it seems probable that deficits in the oral region may effect both motor and sensory functions. One of our consultants summarized the status of knowledge with respect to the articulatory problems associated with cerebral palsy as follows:

> It is difficult to indicate what is our present knowledge regarding disordered articulation in cerebral palsy. There is a dearth of systematic investigation of this problem and we know very little "for sure." The field is dominated by opinions with several "systems" of therapy currently receiving attention. Probably the greatest research need is for a conference to develop guidelines for scientific attack on the problem.

d. Dysarthria. Articulation disorders associated with loss of neuromuscular control due to lesions of either the central nervous system or the peripheral nerves are given the generic name dysarthria.

Previous discussion has considered some of the conditions that give rise to the speech symptoms of dysarthria, e.g., the articulation problems associated with peripheral lesions and with cerebral palsy. In addition to the cerebral palsy, the specific central nervous system lesions which produce the dysarthria may be associated with a variety of causes. For example, dysarthria is a frequent accompaniment of dysphasia and, of course, may result from the same basic causes, e.g., cerebral vascular accident, head injury, etc. Dysarthria may also be an accompaniment of such diseases as: Parkinson's disease, amotrophic lateral sclerosis, and multiple sclerosis. Until recently most of the information available in the literature concerning the articulatory symptoms of dysarthria was of a very general nature. It has usually been given only superficial attention in speech pathology textbooks. Discussions in clinical neurology textbooks are usually brief and of a very general nature. Within the last five years a number of persons have become interested in applying objective measurements to the speech symptoms of dysarthria in an effort to provide a more precise description of the nature and range of these symptoms. However, such scientific studies are just emerging and the data available at this date are fragmentary and meager.

B. *Research Needs.*

In a very important sense one of the most critical needs for further research concerning pathologies of the speech production system is for more comprehensive understanding of the normal speech producing mechanism. It is an obvious, but sometimes overlooked, fact that information concerning pathological conditions and their effects can only be interpreted and understood by appropriate comparison to data concerning pathological conditions and their effects can only be interpreted and understood by appropriate comparison to data concerning the normal system. As has been indicated in the previous section, there are numerous gaps in our understanding of the normal speech production processes. To the extent that this is so, we are handicapped in giving complete and adequate interpretation to data concerning pathological conditions. Despite this, however, we can recognize the need for data which will permit us to describe more completely and more exactly the nature of pathological conditions affecting the speech mechanism and the range of speech and voice symptoms which are found to be associated with these pathologies. Our knowledge of these conditions and their effects on speech will thus be enhanced, even though we still lack comprehensive data and well substantiated theory concerning many aspects of the normal mechanism and the normal function.

The theoretical framework provided by comprehensive and well developed models of the normal mechanism and its functions would also have the virtue of providing guidance for the selection of particular research problems and issues which are most urgently in need of study. However, even without such models, certain areas of need are obvious. It is these needs which are largely dealt with in the following paragraphs.

1. Respiratory Mechanism. As pointed out in the previous section research data concerned with the respiratory processes required for normal speech are meager. The whole topic of speech respiration and the control of respiratory processes during speech is, in one sense, a neglected area. This is even more true of our understanding of the speech respiration processes under various pathological conditions. As previously noted methods are now available for making numerous kinds of quantitative measurements which are essential to the precise description of the physiology of speech respiration. Thus, many of the basic tools needed for significant and detailed descriptive research are available.

a. Need for research concerning limits. One of the important needs for information which will lead to a better understanding of the effects of various types of pathological conditions on speech production processes is for data concerning the limits which define the range of relevant conditions within which normal speech respiration can occur. In general this kind of information cannot be obtained from studying normal subjects and must necessarily depend upon careful analytic study of subjects exhibiting various types of pathology. Such information will, of course, make an important contribution to our overall understanding of the speech production processes in both normal and the pathological situations. This point can be made more concrete through the use of several examples.

(1) Requirements for minimum lung volume. Current data on speech respiration lead to the general conclusion that ordinarily conversational speech requires no more than a small part of the lung capacity of the normal mechanism. For example, tidal air flow during conversational speech may be of the order of one-half liter, whereas the vital capacity of the individual may be four and one-half to five liters. However, we do not have good information concerning how severely reduced the lung capacity can be without an appreciable effect on an individual's ability to produce good speech. Such information can only be obtained by careful descriptive studies of persons having pathological conditions which reduce their functional lung volumes. Such descriptive studies need to be carefully done. They need to take into account the fact that minimum requirements are related both to the absolute amount of air available and to the adequacy of the control of expiratory pressures and flows.

(2) Airway resistance. In the normal speech mechanism the significant resistive load against which the respiratory mechanism develops the expiratory pressures required for speech consists of both the laryngeal resistance that is characteristic of an adducted phonating larynx and the resistance due to articulatory closure and constrictions occurring in the oral cavity. The constant, passive resistance due to friction of the air way walls and other factors not associated with the dynamic articulatory and phonatory functions of speech are relatively negligible in the normal systems. However, this may not be true for certain types of pathology. Some disease conditions provide a general increase in the constant resistance presented by the air way, and thus increase the load into which the respiratory system must work. The effects of such increase in constant resist-

ance on speech and voice production are essentially unknown.

(3) Compliance of respiratory system. Physiologists have been concerned with the parameter of compliance of the respiratory system, in part because reduced compliance is a characteristic of certain disease states. However, researchers concerned with the study of normal speech respiration have taken little note of this parameter, presumably because it is assumed that speech taxes the normal respiratory systems so little that changes in compliance would not be significant. However, in a pathological state which may involve both reduction of lung volume and inadequate neuromuscular controls, the parameter of compliance may become significant in relation to speech and voice production. Its effects can probably only be studied in selected subjects having a range of pathological conditions that would enable variations in compliance to be observed.

(4) Neuromuscular control of expiratory pressures and flows. As previously indicated some investigation of the control of expiratory pressures and variations in air flow for a small number of selected subjects having cerebral palsy has been reported. However, much more needs to be done to provide an adequate understanding of the relationship between functioning of the expiratory muscles, e.g., the intercostals, and the valving functions inherent in phonation and articulation. In pathological subjects all of this needs to be understood in relationship to reduced lung function associated with volume change, increased air way resistance, and the relation of air way resistance to conditions of the larynx and nasal passages.

b. Need for study of dynamic relationships. A great deal of our knowledge of reduced respiratory function in pathological cases is concerned with absolute measurements such as vital capacity, or with lung function tests involving non-speech tasks. However, the requirements placed on the respiratory system during speech appear to be sufficiently specialized so that information from such absolute measurements or from non-speech function tests is difficult to interpret in relationship to speech production. Thus, we need information concerning the dynamic respiratory activity involved in speech and the extent to which such function is reduced as a result of various pathological and disease conditions. As previously indicated, many of the observational tools for such descriptive studies are not available.

2. The Larynx. As noted in the previous section the major proportion of our current information concerning laryngeal pathologies has been derived from clinical experience. Although a beginning has been made in the collection of data under controlled conditions by means of relatively precise instrumental techniques, the quantity of such data currently available is still very meager. Consequently, it can be generally stated that an important research need is for more precise and quantitative descriptive information concerning pathological states of the larynx and their associated physiological and acoustical consequences.

There is a definite need for much better incidence data than are currently available. Current information on the prevalence of various types of laryngeal pathologies is almost exclusively based on patients who come to doctors' offices or to clinics. Such information provides no index to the number of individuals who are actually in need of service but do not seek it. Even so, current information indicates that the prevalence of laryngeal disease is sufficient to mark it as a major medical problem. In the few instances where surveys to ascertain the prevalence of laryngeal pathologies have been carried out, the data have revealed a surprisingly high incidence. An example is a recent survey of school-aged children in a large midwestern city in which it was found that the relative frequency of occurrence of inflammatory lesions was high as 5 per cent. Although comparable data for adults are not available, it is probable that the frequency among adults is at least as great.

There appears to be good reason to believe that certain characteristics of our modern society and modes of living are contributing to an increase in laryngeal pathology. For example, trauma resulting from injuries to the neck in automobile accidents appears to be on the increase. Also, as a result of greater longevity in our modern society, degenerative conditions affecting the larynx are likely to be a matter of concern to the clinician in increasing numbers. Degenerative lesions, such as amyloidosis, and loss of function associated with old age require continuing investigation.

There has been little research concerning the disrupting changes of the larynx associated with disease or injury, such as, changes in the laryngeal joint structure or the ligament and membranes. The laryngeal joints are arthroidal in type having a synovial lining, joint-space and supporting structures. They are subject to injury, infection and arthritis, in the same way as other joints. Information concerning the disruptive changes affecting these laryngeal structures is needed not only for better understanding of the possible effects of disease and injury, but also in relationship to possibilities for successful laryngeal surgery.

The question of the relationship of vocal abuse to laryngeal pathology is a very important one for the clinician. Although there is general agreement that misuse of the voice may have some relation to the development of nodules and contact ulcers, the major share of current evidence is based on case reports and clinical impressions. Current information is not sufficient to establish definitive conclusions and more extensive data, involving larger numbers of patients, and careful data collecting processes are needed to establish these relationships with adequate documentation.

Relatively little is known concerning the logical basis for several types of laryngeal growths. A plausible hypothesis that badly needs research investigation is that such growths may have immunologic or auto-immunologic etiology. Juvenile papillomatosis, papillomas (in general), granulomas and cancer have all been mentioned as possibly being immunologic in origin. Despite this, immunology is a relatively undeveloped area of research interest with respect to the larynx. Some information is available regarding keratosis, smoking, and the development of cancer of the larynx. Most of the work has been statistical and little has been done in controlled studies in the experimental laboratory. Additional research is greatly needed and should be encouraged.

In the section on normal speech production mechanisms, mention was made of the need for additional anatomical information concerning the fine structure of the intrinsic muscles of the larynx and the nature and distribution of neural innervation of the laryngeal nerves. Such information is also needed to provide a better basis for an understanding of vocal cord paralysis and their effects on phonation. Witness the fact that clinical reports on laryngeal paralysis patients indicates that no apparent cause can be found for about one-fifth of laryngeal paralysis cases.

3. Pharyngeal-Oral-Nasal System. In a foregoing section concerned with research needs in speech respiration, the point was made that one of the most pressing needs, so far as understanding pathological states which affect the respiratory system and the effects of these conditions on speech and voice production were concerned, was for more complete and precise information concerning the normal functioning of the respiratory system during speech production. The same point holds true to at least as great a degree with respect to the understanding of pathological conditions affecting the vocal cavity transmission system and the functioning of the articulatory mechanism. As previously noted research has clearly shown that the articulatory function is much more variable and far more complex than had been assumed until quite recently. Generally speaking, discussions of the speech deficits associated with the various pathological states have not taken adequate account of this recent information concerning the dynamics of continuous speech. Obviously this represents a situation that should be corrected. However, much more complete information concerning the dynamics of normal speech articulation and more adequate models of articulatory functioning and control are needed to provide a basis for interpreting data concerning the speech deficits associated with pathological states. As one example, it has become clear that physiological functioning of the articulatory mechanism cannot be appropriately analyzed as a simple linear string of consecutively independent phonetic events. If this is true for the normally functioning articulatory mechanism, it must be equally true that the deficits in function related to pathological states must be interpreted in relation to the contextual variations of speech sound production and in relation to the overlapping phonetic movements denoted by the term, co-articulation. As another case in point, recent research indicates that not only is the articulatory mechanism involved in the production of various vowels and consonants, but in addition that the constrictions and occlusions associated with these articulatory movements have important relationship to the control of the expiratory flow of breath during speech. It is now widely recognized that to adequately account for speech articulation any conceptual model must take far more account of the aerodynamic aspects of the speech production processes than has been done by most phonetic theories. Without more complete data and more adequate theoretical development, inferences with respect to the effects of pathological conditions must necessarily be highly speculative, but it is probable that the aerodynamic effects are as important, if not more so, than are the details of position and movement that have previously received the most attention. Moreover, the lack of adequate and properly coordinated valving in the oral-nasal-pharyngeal mechanism may have a greater effect on speech production than would be apparent from an analysis which considers only the phonetic effects, as these can be observed with respect to the articulation of specific speech sounds.

A specific instance of the foregoing point relates to the lack of adequate pharyngeal valving which is associated with cleft palate or pharyngeal incompetence. Not only does this have an observable effect on the production of certain speech sounds which are normally non-nasalized; there is the additional effect that the lack of velopharyngeal valving removes one of the important elements of the breath control system. Hence, the entire load on the respiratory mechanism is likely to be altered. Because of the nasal escape of air, the volume flow required for adequately audible speech will be increased. The amount of effort required of the individual and the total amount of work required of the respiratory system will doubtless be greater. Although there are some data which show that the average volume flow of expired air during speech for cleft palate individuals is greater than that for normal speakers, this is a matter which has not been well studied and on which research is needed. Its importance has only recently begun to be appreciated. Moreover, it is only one example of the point here being made that there is an interaction between articulation and aerodynamic respiratory control which needs to be studied in connection with all types of articulatory function.

Another area in which research is needed concerns the possible effects of pathological states on the feedback control systems involved in articulatory movements. This too is an area in which understanding concerning the effects of pathological states depends on better understanding of the normal articulatory processes. As previously indicated, the study of feedback control mechanisms in normal speech is currently in a primitive state and much remains to be done. It seems obvious that research studies of the normal processes and of pathological conditions must go hand in hand.

IV. SPEECH DISORDERS WITHOUT KNOWN ORGANIC PATHOLOGY

A. *Introductory Remarks.*

The disorders that we shall be concerned with in this section are those which are frequently designated by the term functional. Since this term can have several meanings, it is probably appropriate at the outset to discuss these several meanings briefly In relation to the present context.

The first, and perhaps most straightforward meaning of the term functional disorder, is that which denotes a disorder for which one can not specify an organic or structural etiology, i.e., the relevant features of the organism appear to be normal, so that it is assumed that the capability for normal function exists. Thus, the term functional denotes a deficit in the actual functioning of the organism, although such deficit cannot apparently be explained in terms of the capability of the organism for normal functioning. Obviously, the fact that one cannot specify an organic deficit, or even establish a strong presumption for an organic deficit does not completely rule out the possibility that the true explanation is, in fact, some type of pathological state that has not been detected. Thus, when used in this sense, the term functional must necessarily be a catch-all, and the differential diagnosis of functional disorder as opposed to organic pathology as an etiological classification is necessarily the result of a process of elimination.

A second meaning for the term functional that is frequently encountered is one which denotes a disorder which is thought to be related to a psychological factor or factors such as emotional maladjustment or personality disorder, etc. In such cases it is often presumed that the psychological problem is the more basic one and that it will need to be resolved before the functional symptom can be eliminated or minimized. Stated somewhat differently, this use of the term functional implies that the disorder so classified is a symptom of a more basic and underlying psychological disturbance.

The third meaning of the term functional, which is sometimes encountered in the literature, is used to denote a residual of inadequate functioning which remains despite the fact that the organic deficit which had been presumed to be its underlying cause is no longer operative. That is, the organic condition which once explained the deficit of function has presumably been corrected. Thus, although normal function has not been restored, the capacity for normal function is thought to be present. All of these usages have some application in the following discussion. In most instances, the specific meaning should be reasonably clear from context. If this does not seem to be the case, the particular meaning which is relevant at any point will be made explicit.

B. *Stuttering.*

1. Current Status of Contemporary Knowledge. The problem denoted by the term stuttering has been one of the most perplexing of the various problems of concern to the clinician and researcher in the area of speech production. The clinical research literature on stuttering is perhaps more voluminous than that concerned with any other speech or language disorder. Researchers have been engaged for many years in attempting to provide more and more detailed and complete descriptions of the behavior which we label stuttering and of seeking possible causes for such behavior, or at least, providing possible explanations for its development. Despite all of this there is still a wide diversity of opinions concerning the basic nature of stuttering, and particularly concerning what are thought to be the significant factors that are causally related to its development.

The researches which have been carried out concerning the causes of stuttering can be grouped into three main categories. The first category includes a group of studies which have sought to determine whether or not stuttering can be explained as a symptom of some type of constitutional or organic deficit. Included within this group are studies which have attempted to investigate possible genetic factors and studies which have attempted to demonstrate organic differences between stutterers and nonstutterers by showing one or more of the following: (a) differences in laterality of cortical dominance and central nervous system control, (b) biochemical differences, (c) neuro-muscular differences, such as differences in speed with which repetitive movements can be made, (d) differences in electroencephalographic tracings, (e) differences in breathing patterns during speech, (f) differences in reactions to certain types of drugs, etc., etc. A few general statements can be made concerning the results of these researches. First, although there is some lack of agreement among results of various studies, there is general consensus among most investigators that the data so far obtained provide little support for the hypothesis of a constitutional difference between stutterers and nonstutterers. In general any differences found have been very small and usually not statistically significant. In some instances where specific functional differences have been demonstrated (for example, with respect to disruptions of breathing patterns and peculiarities of electromyographic muscle records) the peculiarities of the stutterer's patterns appear highly specific to instances of disruption of speech fluency, and to be best interpreted as aspects of the stuttering symptom, rather than causally related to the stuttering disorder.

Researches of the second type have attempted to test the hypothesis that stuttering is a symptom of a fundamental neurosis or psychoneurosis. Much of the evidence cited in support of this viewpoint has been based on clinical reports. As scientific evidence, such reports suffer from the weakness that the reporting clinician starts with the basic assumption that a neurosis exists. Thus, the evidence cannot logically be regarded as testing the hypothesis. A number of studies have attempted to use more objective techniques to determine whether stutterers differ systematically from nonstutterers with respect to emotional adjustment characteristics or other aspects of personality structure. However, these studies have failed to show that stutterers as a group are basically different from nonstutterers in their general emotional adjustment or personality structure. Such anxiety symptoms and other indications of maladjustment as tend to be found among stutterers appear to be related very specifically to their speech problems, so that they may reasonably be interpreted as the result of the speech handicap rather than as a cause.

The third type of research effort has been directed at describing the stuttering symptom itself as completely and precisely as possible, including a thorough investigation of the conditions under which stuttering tends to vary. Included in this category are studies of the factors which seem to be associated with increases in stuttering nonfluency or the conditions under which such nonfluency appears to be relatively absent, the course of the development of stuttering in the individual from the time when it is first noticed (usually at about three years of age) through adulthood, the way in which the stuttering symptoms change through this period of development, and the nature of reactions to stuttering symptoms both by the stutterer himself and by other listeners. This third category of studies includes probably the largest proportion of all researches concerned with stuttering. The nature of these studies and the results are so varied as to make a brief summary very difficult. Insofar as inferences are possible with respect to the causes of stuttering, the interpretation on which there seems to be the greatest amount of agreement is that stuttering is a learned response without organic basis. The conditions which are thought to underlie the learning of this abnormal response tend to be social pressures, often associated with the individual's family, which produce anxiety in the individual concerning his ability (or lack thereof) to manage his own speech in a normal fashion. As a result of these pressures the individual is made abnormally conscious of ordinary, normal mistakes and interruptions of fluency in his own speech to the extent that he becomes anxious and hypertense concerning such mistakes and interruptions. At the age of three, or thereabout, many such mistakes and interruptions are to be expected as a result of the child's ordinary normal speaking behavior. However, the anxiety and hypertension due to social pressures to speak flawlessly tend to accentuate their frequency and the child's reactions to them tend to be intensified. Over a long period of time these hypertense reactions are thought to be reinforced to the extent that the nonfluent anxiety response becomes extremely persistent and difficult to eradicate.

Despite the very large amount of research on stuttering that has been done, each of these three widely divergent points of view with respect to the nature and causes of stuttering still has its advocates. Those who hold the opinion that stuttering must have a constitutional basis do not find that the research to date provides an adequate basis for ruling out this possibility. Likewise, the group that holds to the view that stuttering must be a symptom of an underlying neurosis does not see in the data sufficient conclusive evidence for rejecting this hypothesis. Because of the considerable difficulties of objective research in the area of abnormal psychology this is a very difficult hypothesis to establish or to disprove conclusively. The third point of view is likewise held by a substantial number of investigators. Since the persons holding these differing points of view tend to interpret the data in different ways depending upon their particular systematic biases, no immediate resolution of these differing opinions appears to be in prospect.

Because of the lack of agreement with respect to systematic views concerning the probable nature and causes of stuttering and because of their varying interpretations of research data, it would be difficult to find agreement among the groups concerning what researches are most needed in the immediate future. Certainly, to the extent that research procedures can be developed which will provide additional data concerning possible organic or structural causes for stuttering, or possible relationships to underlying personality and emotional problems, such researches should be encouraged. However, it is probably fair to say that the prospect for increasing our knowledge of the stuttering problem by a large research effort in these directions is not very bright. One fact about which there can be little controversy is that the stuttering symptom appears to be one that can be modified under the influence of or in association with, a substantial number of environmental variables. Clinicians have long taken advantage of this characteristic of stuttering, and it is the modifiability of the stutterer's nonfluent behavior that constitutes a large part of the basis for the remedial procedures currently utilized in clinical treatment of this disorder. However, much more needs to be learned concerning the relationships between various types of manipulable variables and their influence on speech. Better information is also needed concerning the factors which tend to cause stuttering to change as the individual becomes older, so that the stuttering symptom becomes more complicated and more resistant to modification. Such information would be extremely useful in the development of improved treatment procedures and would be significant as well because of what it would reveal concerning the nature and causes of the disorder.

C. *Articulatory Problems.*

Many types of speech disorders have an articulatory problem as their major symptom. For example, a substantial part of the problem of the child with a cleft palate can be considered to be articulatory in nature. Likewise, one of the most significant problems of the child with cerebral palsy is that his articulation is defective. On the other hand, there are a substantial number of articulatory problems for which no such obvious organic basis can be demonstrated. It is the latter problems that we are concerned with in this section.

Because there is no demonstrable organic explanation, a common explanation for the lack of adequate speech in these instances is that of faulty learning. One general area of research with respect to such problems may be characterized as a search for contributing factors which could retard or interfere with the development (or learning) of normal articulatory skills. For example, researches have sought to determine whether or not persons with functional articulatory disorders may be deficient in their ability to make certain auditory discriminations, such as their ability to discriminate among pitches of tones, the ability to discriminate among complex auditory patterns, or the ability to discriminate among different vowels and consonants. The research evidence is not as conclusive as might be desired, but there is some indication that a specific lack of the ability to discriminate among speech sounds may be a contributing factor. It is not clear, however, that this lack is due to some innate defect of the auditory system. Instead, the lack of speech sound discrimination may itself be an acquired disability, i.e., due to faulty learning.

A somewhat different line of inquiry has shown quite conclusively that there is a frequent association between poor articulatory development and poor development with respect to language skills generally. Thus, children who are retarded in reading are more likely to have articulatory deficits than are children who read normally for their respective ages. Also, children who show retardation with respect to vocabulary development, development of verbal output, development in the ability to use complex sentences, etc., are likely to also show retardation in the development of articulatory skills. On the other hand, there appears to be a substantial number of children for whom the deficiency in articulation appears to be a rather specific type of disability with little relationship to retarded development in other language skills.

There is also evidence indicating that on a statistical frequency basis development of normal articulation is related to general intellectual development. That is, children for whom the classification of mental retardation is appropriate show a substantially higher incidence of defective articulation than do children of normal intelligence. However, there are many instances of functional articulatory problems which seem completely unexplainable on such a basis.

The incidence of children in the early elementary grades who have deviations in articulation of sufficient degree to constitute a significant educational and social handicap is substantial. Estimates run as high as five percent of the primary age school children. In developing remedial programs for such children a major problem is that experience shows that a large proportion of these children will develop normal speech in due course of time with little or no specialized attention. On the other hand, for some of these children the problem will continue and may constitute a significantly handicapping condition throughout their school years and into adulthood. Current knowledge does not provide sufficient basis for differentiating between these two groups and research which would provide valid procedures for such differential diagnosis would be a major contribution and is badly needed.

Since it is probably valid to consider the development of articulatory skills as part of the more general process of language development, our understanding of functional articulatory disorders will doubtless be enhanced as we learn more about the whole process of language learning and development. Recently we have seen a surge of interest and research effort in this area. In large part this acceleration of research in language development is due to the efforts of the group that are identified with the term psycholinguists. By applying the concepts and principles that have recently been developed in the field of structural linguistics to the investigation of language acquisition, this group has opened up new lines of inquiry that appear to be very promising. Presently our knowledge concerning the acquisition of articulatory skills is largely restricted to normative data concerning the ages at which children may be expected to have mastered the articulation of the various phonological units of the language. As valuable as such data are they provide little information concerning the actual processes by means of which articulatory skills are learned.

It is probably obvious that improvement in the understanding of functional articulatory problems must be related to an improvement in our understanding of the normal articulatory processes. As previously indicated, substantial gaps still exist in our ability to account for the fundamental physiological and neurophysiological events of speech articulation. Until these gaps are replaced by adequate knowledge, we shall doubtless continue to be unable to give account of the dynamics of defective articulation.

D. *Functional Voice Disorders.*

The problem of "vocal abuse" and its possible relation to pathological states of the larynx has previously been discussed. In one sense, such vocal abuse constitutes a functional voice disorder. In such instances the supposition, for which there is some supporting evidence, is that poor vocal habits, overuse of the voice, excessive amount of loud shouting, etc., can produce an inflammatory condition which, if continued for a sufficient time, may result in permanent tissue changes.

In addition to these cases in which pathology may be accounted for by dysfunction, there are numerous reports in the clinical literature of individuals who have significant vocal problems of sufficient severity to constitute a handicapping condition which apparently cannot be accounted for on the basis of organic pathology. Of course, in some of these instances it may be a plausible hypothesis that organic pathology sufficient to account for the vocal condition exists, but has gone undetected.

The vocal symptoms of such functional voice disturbances include a wide range of abnormal voice characteristics. For example, one class may be characterized as disorders of pitch. This class would include a person who habitually uses a pitch level badly suited to his age and sex and possibly to his vocal mechanism, also a person whose pitch usage is so monotonous as to rob his voice of normal expressiveness. Another class includes significant deviations in vocal quality, such as abnormally nasal voices, voices marked by harshness, hoarseness, breathiness, etc. One of the difficulties in investigation of functional voice disorders is that the terminology which various investigators have used to describe voice quality characteristics is so non-standard that different investigators may use the same term to characterize quite different vocal attributes. Thus, it becomes difficult to classify different voices in ways which will be understood by other individuals or to otherwise meaningfully deal with the variables of voice quality problems.

Evidence from some research studies indicates that certain voice quality problems may be causally related to habitual usage of a pitch which is unsuitable to the individual's vocal mechanism. That is, the quality problem may be secondary to a disorder of pitch. There is also evidence that cultural factors may account for usage of certain vocal pitch ranges which are not appropriately suited to the individual's voice, especially among women. For example, research on pitch levels of adult women suggests that substantial numbers of such women use pitch levels which are too low within their pitch ranges to be optimal for good voice production. It is at least plausible that the motivation for this excessively low pitch usage is social and cultural pressure. Moreover, there is evidence suggesting that such excessive low pitch usage may result in breathy and hoarse voice qualities.

Recently there has been considerable research interest in a particular type of vocal phenomenon that has been labeled "vocal fry," and which has commonly been thought of as constituting a voice disorder. The evidence from these studies suggests this type of phonation is actually a normal aspect of the speech production of all persons. According to this view "vocal fry" should not be considered a voice quality disorder, but rather a normal register in the very lowest part of an individual's pitch range. Although most persons seldom use this register for sustained phonation some use of this register occurs as a normal aspect of speaking, especially at the end of downward pitch inflections, as at the end of sentences. This research suggests that some types of functional voice disorders that are usually thought of as problems of voice quality may actually be an excessive use of this extreme low pitch register. Whether or not long continued excessive use of "vocal fry" constitutes vocal abuse that may result in permanent tissue damage is an unanswered question.

Hypernasality, or excessively nasal voice quality is a type of voice disorder that in some instances is thought to be functional. Such excessively nasal quality in speech is, of course, more related to the functioning of the velopharyngeal port mechanism than to inadequate laryngeal functioning. Clinical experience has shown that some individuals present excessively nasal voices even though their velopharyngeal mechanisms appear to be capable of normal closure.

In addition to the foregoing, there are vocal symptoms without organic basis which are apparently associated with psychiatric problems. For these the psychiatric problem is usually thought to be the primary one, and the voice problem is considered a secondary symptom. Recently, there has been some interest among psychiatrists in developing quantitative measures of the vocal symptoms of emotional disturbance as a possible aid to psychiatric diagnosis.

As with functional disorders of articulation, one of the important research needs relating to functional disorders of voice is for improved information and understanding concerning normal voice and speech production. One particular need is for data based on large samples of subjects having normal voices. Currently the major proportion of information about normal voice production is based on small numbers of carefully selected subjects. Although investigations of this kind may yield valid data concerning typical voice characteristics of normal speakers, knowledge concerning variability of characteristics and the limits that the normal range define is not obtained from such studies.

Research in the area of functional voice disorders would be greatly advanced if clinicians and researchers could come to some substantial agreement concerning definitions and nomenclature. As previously stated there is almost no agreement concerning the terms to be used in describing voice problems, the categories into which voice disorders may be classified, or the criteria for classification. Without agreement on these fundamental matters as a beginning point, it is essentially fruitless to attempt to study the physical or physiological characteristics of any particular kind of disorder. At the present time this matter of classification and terminology can only be characterized as chaotic and confused. The major source of this difficulty is that clinicians, voice therapists, voice teachers, etc., have frequently developed their own descriptive nomenclature whose terms have meaning to them, and perhaps to a few others (e.g., their students), but which are not objectively defined in any sense and which do not have specific meaning for others. An alternative approach to this problem which might have virtue, although at first glance it seems laborious, is to attempt exhaustive objective study by means of physical and physiological tests of a large sample of voices which persons would generally agree to exhibit abnormalities. From such data it might be possible to evolve a classification system based on more objective criteria and to obtain reasonably good agreement on such a system.

As indicated in the foregoing section on normal voice, technology is now available for making physical and physiological observations concerning laryngeal function during phonation. Generally speaking, however, these procedures have not been applied to the study of functional voice disorders. The number of such studies can almost be counted on the fingers of one hand. Among this small number some are primarily illustrative in nature, having as their primary purpose the demonstration of a technique and its application to the study of a disorder. What is needed is far more extensive research based on sufficient numbers of subjects to provide reasonably reliable statistical data. Such information would provide a basis for more precise description of the physical and physiological nature of the disordered function and should also have significant application to differential diagnosis.

A few specific examples may suffice to make the above general points a little more concrete. Consider an individual who has a relatively weak and breathy voice. Clinical observations suggest that a typical such individual may also have a limited pitch range and probably a limited vocal intensity range. An ordinary laryngoscopic examination is unlikely to really reveal anything that would be of concern to a laryngologist, or that would be classified as pathological in nature. Also, an ordinary laryngoscopic examination will yield very little data about the functioning of the larynx for phonation. For example, how does the pattern of glottal vibrating movement of such an individual compare to that of the individual with normal voice? Is the open-quotient of the glottal cycle comparable to that of an individual with normal voice? Does the open-quotient vary with pitch in the normal fashion? How does the pattern of vocal fold movement vary with changes in intensity? Is this variation within the normal range? How does the length of the vibrating glottis change with change in pitch? Is this length change as great as would be expected for normal voice? How do the subglottic pressures produced for phonation compare to those expected for normal voice? Does the subglottic pressure vary normally with respect to change in frequency and intensnity?

These are by no means the only questions that one might ask, nor do the answers to these questions constitute the only significant descriptive data which would give us better information concerning the presumably functional voice disorder of such an individual. The points to be made are: (1) Without such descriptive information, we really know very little about the actual functioning of the individual's vocal system. (2) At the present time data of the type suggested are almost completely lacking with respect to functional voice disorders in general. (3) The technology for filling in this gap in our knowledge is available.

Another example concerns the relationship between functional quality disorders that are frequently characterized by such descriptive terms as hoarseness and harshness. Recent investigations have indicated that the wave forms produced during normal vowel vocalization are characterized by a certain degree of aperiodicity. It has also been shown that, in the presence of significant laryngeal growths, such aperiodicities of vocal wave-form are frequently increased by a relatively large factor. However, there has been very little study of glottal wave-form aperiodicities among individuals whose vocal qualities show characteristics of hoarseness, or harshness, but who show no evidence of laryngeal growths.

The foregoing are but two examples of areas in which our knowledge and information concerning laryngeal functioning among individuals who are said to have functional disorders of voice can only be characterized as deficient. Moreover, such deficiencies are not likely to be filled in in a normal course of clinical study of individuals having voice disorder complaints. If we are to achieve better information and understanding in these areas, systematic research is required.

V. MANAGEMENT AND TREATMENT

A. *Medical and Surgical Treatment.*

1. Reconstructive Surgery. In the past the two major areas in which surgical management has made a contribution to the reconstruction of the organs involved in speech, or the restoration of normal voice and speech function, have been (1) the area of cleft lip and palate and (2) the removal of laryngeal growths which interfere with normal phonation.

In the case of cleft lip and palate reconstructive surgery has made very substantial gains in the years since World War II. It is now generally agreed that the primary goal of such surgery is to achieve a mechanism that can function as well as possible for speech. This principle has come to guide diagnostic decisions concerning surgery in a number of ways. For example, attempts are usually made to time the surgery and other management procedures so as to interfere as little as possible with the processes of normal speech and language development. The repair of the lip is usually begun as early as possible. Primary care is usually carried out in very small infancy, although secondary procedures to remove scars, to improve the mobility of the lip, etc., may be carried out at somewhat later ages. The timing of the closure of the palatal defect varies somewhat among different surgeons and will in any case take into account the nature and the extent of the defect, etc. Each patient requires individual evaluation. In addition to the question concerning the possible relation of the surgical procedure to the development of speech and language, account must be taken of the effect of the surgical procedure on dental and facial growths, cosmetic effect to be expected, effects on the general health of the individual, possible relationship of the surgical procedure to the development of dental structures, etc. Progress in recent years has been sufficient so that in a large number of cases, where the palatal defect is not very extensive and where a considerable amount of tissue is present, a surgical procedure often succeeds in achieving an excellent speech result. In the optimum case, the individual is able to speak with little or no detectable abnormality even without special remedial speech therapy. In a substantial number of additional cases the potential for good speech function can be created, but this potential will need to be developed by appropriate remedial speech procedures. Unfortunately, although the frequency of success as measured by a satisfactory speech result has increased substantially, failures still occur, some of which cannot be adequately explained in terms of present knowledge.

The problems inherent in research to improve management and treatment procedures are difficult ones. The evaluation of treatment results can only be made over a relatively long period of time; the number of factors which contribute to the success or failure in the individual case are numerous, and there are extremely complex interactions among these factors. Consequently, such research is both demanding and expensive. Longitudinal studies of considerable duration utilizing the best possible and most nearly standardized possible procedures for evaluation are required. Even with such care, evaluations based on comparisons among patients will be difficult, because of the very great complexity of variables involved and the very large amount of individual variation among patients. Consequently, a large subjective factor is inevitable in such research. Nevertheless, such research is necessary if we are to continue to learn and if we are to make any evaluation of the results of management procedures beyond a gross clinical impression.

As previously stated, laryngeal surgery which contributes to the restoration of normal function was, until the recent past, largely restricted to the removal of benign growths. Recent developments in techniques and principles of laryngeal surgery give promise of voice improvement in some cases formerly seldom thought to be treatable. It is also proving possible to preserve at least usable voice in some instances in which this would not previously have been possible. However much remains to be learned.

The most frequent voice rehabilitative measure employed for unilateral cord paralysis has been the use of synthetic pastes injected into the paralyzed cord. While improvement of voice is dramatic, little is known of the ultimate fate of these pastes and their later effect in the patient. More basic information is needed regarding the innervation capabilities of the recurrent laryngeal nerve, and the movement of the vocal cords.

Significant progress has been made in the surgical treatment of laryngeal cancer while voice and function of the remaining larynx by extensive, but subtotal, removal of the upper or cordal portions of the larynx. This mode of therapy can be equal to more radical operations in the treatment of cancer. However, it introduces a host of problems and needs for research with respect to the remaining reduced structure of the larynx. The principles used in subtotal surgery for cancer of the larynx should be applicable also in the treatment of traumatic injuries to the larynx.

The depth of knowledge necessary for understanding the larynx and its function in communication requires more than study of normal and abnormal vocal cord movement and its dependency upon good respiratory mechanics. A case in point is the need for more information of anatomic-physiologic reflex relationship with the nose and lung. Factors necessary for maintaining sufficient integrity of the crippled larynx so that it can function for speech, and those necessary to maintain adequate functions for deglutition and airway, need to be determined. Clinical trials are not progressing rapidly because of the lag in basic research in these areas. More specifically, normal larynges have usually been studied along with the pathologic larynges as far as electromyography, cord mobility and sound output are concerned. However, little work has been done which relates or defines, other than in gross terms, why in some cases, an incompetent glottis leads to aspiration with deglutition. Voice, although hoarse, is reasonable for communication in either situation.

Notable technical progress has been made in the immediate success rate of auto– and homotransplantation of the canine larynx. Transplantation should not be attempted until the risks of the immunological rejection phenomenon of the donor larynx are determined in the recipient. The safety of the operation must be determined and weighed against the known security of total laryngectomy. Thus, transplantation of the larynx in humans should be delayed until more basic information has been validated in animals.

Further work needs to be done concerning revascularization, reinnervation, functioning integrity (sound, speech, swallowing, airway, and respiratory dynamics) and acceptance of the transplant by the recipient over a long period of time.

Another need which can be met by appropriate clinical investigation is for further data on the dynamics of the tracheo-pharyngeal, speaking-tube operation (Asia).

2. Drug Therapy. This area of clinical research offers a great potential for improvement in certain pathologic entities. Examples are: investigation of certain drugs that promote reinnervation of the larynx, use of cortisone in arytenoid arthritis, thyroid extract for reduction of laryngeal polyps and chemotherapeutic drugs for laryngeal or pharyngeal cancer. There are hopeful possibilities that such agents, when available, can change the entire picture regarding cancer therapy in the larynx, pharynx, and oral cavity.

B. *Educational and Rehabilitative Management.*

The field of speech pathology has developed very markedly over the last 40 years. A great part of the advances that have been made with respect to remedial procedures that can be used in helping individuals with speech and voice disorders have been the result of clinical experience and empirical "cut and try" procedures. Although experience has proved these procedures to be effective in a large number of cases, much remains to be learned. In fact, the area of clinical research is probably one in which the needs for expanded effort are most critical.

Past research and development work concerned with clinical procedures have made important contributions to methods of testing and evaluating speech and voice characteristics, to procedures for evaluating related factors, including case history methods, and to the development of normative data needed for clinical evaluation. There has also been a limited amount of work to develop and improve remedial procedures. Some of this has been concerned with specific remedial techniques and with aids and devices of various kinds which have application in the speech clinic.

In considerable part, however, remedial procedures have been developed from experience by applying principles of behavior modification that have been developed in educational psychology, by applying knowledge of the counseling relationship developed in clinical psychology, etc. Much has been done simply on the basis of good judgment, a prior analysis, and trial and error procedures. Recently, however, there has been an acceleration of experimental work that is directly relatable to clinical procedures. One example is the application of programmed learning techniques to the clinical situation. Since a substantial part of remedial work in speech involves learning of new motor skills, or modification of old motor habit patterns, the techniques of programmed learning seem likely to have valuable applications. Also, the paradigm of the operant conditioning experiment has seemed to have possible applications and several investigators have been exploring these possibilities. All of this work appears promising and should be encouraged.

C. *Interdisciplinary Management.*

In a number of areas having to do with speech and voice problems, the development of interdisciplinary teams has proven extremely valuable, both in promoting research and in the development of improved management and treatment procedures. Notable among these areas is that of cleft palate. Teams with a primary interest centered on the problem of cleft palate typically include a cleft palate surgeon, a speech pathologist, an orthodontist and/or prosthodontist, and frequently a psychologist and social worker. Because representatives of all these professions have, or should have, important information to contribute that will enable better diagnostic and management decisions to be made, these teams have generally proven themselves to be effective. However, the principle which makes these teams effective is also applicable in other areas having to do with communicative disorders. Generally speaking, communicative disorders are highly complex in nature. They may involve medical problems which require surgical or other medical treatment. However, in many instances the medical and surgical treatment must be supplemented by the contributions of professional workers representing other disciplines. Oftentimes a full understanding of the case requires a psychological evaluation and an evaluation and analysis of the speech problem that can only be done adequately by persons who have special training in those areas.

Interdisciplinary management teams should be encouraged in all settings in which it would appear that they have a chance of reasonable success. Demonstration projects to establish such interdisciplinary treatment teams on an experimental basis should be encouraged. They should, of course, be encouraged, if not required, to utilize the most effective possible evaluative procedures in order that the success of such projects may be adequately assessed.

VI. TRAINING NEEDS

A. *Types of Researchers Needed.*

Researchers who contribute to our understanding of the processes of speech production and the disorders of these processes come from many disciplines. Even a partial list would include several of the basic science fields, e.g., physiology, anatomy, acoustics, experimental psychology, linguistics, experimental phonetics, etc. Several clinical fields would also have to be included, e.g., otolaryngology, pediatrics, neurology, speech pathology, clinical psychology, etc. Important contributions have also been made by persons from several applied areas, such as communications engineering, computer science, and others. Researchers trained in all of these fields who have a special interest in specific production are needed.

B. *Possible Approaches to Meeting the Needs.*

One view of the task of increasing the supply of researchers who can contribute to our understanding of fundamental speech processes is that what is needed is to accelerate training in all of the fields indicated in the previous paragraph. This represents a very imposing task. Moreover, it appears to constitute a very indirect attack on the problem of increasing the number of researchers whose primary dedication is to the development of new knowledge concerning speech.

As a more direct attack on this problem some universities have been developing specific programs having as their primary purpose the preparation of individuals as teachers and researchers of *speech science*. Programs of this kind have developed under different auspices in different universities. In some instances they are associated with graduate programs for training speech pathologists and audiologists. In other instances the students in these speech science programs have tended to be communications engineers or computer scientists. In other instances linguists predominate. These efforts are too new to have achieved any common pattern among different universities, and it may be argued with some validity that freedom to experiment is far more important than uniformity at this stage.

These programs in speech science have been criticized on the grounds that there is no such field as *speech science;* rather there are *speech sciences.* In other words these critics take the point of view that the persons who can make valuable contributions to an understanding of the physiological phenomena of speech production are physiologists who develop a special interest in speech research, the researchers who can make valuable contributions to an understanding of speech behavior are experimental physiologists who develop a particular interest in speech production, etc. The critics argue further that the attempt to develop a program for training persons as speech scientists must be so multidisciplinary in content and nature that such an individual will inevitably be superficially trained in a number of sciences but will be lacking in competence in any single one of these fields.

The possibility that these criticisms have some valid foundation is too real to be ignored. Certainly directors of training programs, and faculties concerned with the preparation of individuals as speech scientists, must be aware of the dangers expressed by these critics. Nevertheless, the need for a direct attack on the problem of increasing the supply of researchers whose primary dedication is to the study of speech is very great. It does not appear likely that it will be solved in the near future in any case, and it certainly will not be solved by the indirect process of trying to attract an occasional psychologist, physiologist, physicist, etc. to become sufficiently interested in research on speech production so that he will spend the major share of his energy on such problems. Both types of attack would seem to be needed and it would appear that they should be exploited to the largest possible degree. Thus it would seem urgent that support be provided for the development of programs for the training of speech scientists per se. At the same time support should be provided for recruitment efforts which would attract individuals from the basic sciences to devote their efforts to research on speech production.

Another important possibility for increasing the research manpower available for the study of speech production processes lies in increasing the research interests and research competence of individuals who are engaged in the various clinical fields concerned with the disorders of speech. An occasional laryngologist becomes sufficiently interested in the problems of anatomy, neuroanatomy, physiology, etc., which are important to the expansion of our knowledge about laryngeal function during voice production so that he makes important and significant contributions to basic research concerning voice production. Likewise, an occasional speech pathologist develops a sufficient interest in the basic nature of speech production to become competent as a researcher on such problems and to contribute significantly to the body of available research information. The same statement could be made concerning individuals from other clinical fields. However, such individuals are all too few. Greater emphasis needs to be placed on the development of research interest and research competence in the training programs for these clinical fields. Increased attention needs to be paid to the development of persons who may be termed clinician-scientists not only because such persons will increase the total supply of manpower available for the research effort, but because such individuals should be able to make a unique contribution that is very badly needed. Only by developing significant and important research programs in connection with the clinical work concerned with speech disorders will many of the questions concerning the nature and causes of such disorders and how to improve remedial techniques and procedures begin to be answered. It cannot be overemphasized that the clinician who is also a researcher is badly needed in his own right, that he has a contribution to make that cannot be made by the laboratory scientist, and that any inventory of our training needs must be deficient if it does not emphasize very strongly the need for increasing the research interest and competence among those whose primary dedication is to clinical service.

In summary, a reasonable attack on training needs would appear to require support for efforts in several directions. These would include: (1) an increased effort to recruit individuals who have had their primary training in one of the more traditional disciplines to develop a primary interest in research on speech; (2) an effort to train speech scientists, *qua* speech scientists, as is currently being attempted by a number of universities; and (3) the effort to increase the research interest and competence of persons trained in the various clinical fields who provide diagnostic and remedial services for individuals with speech disorders.

VII. SUMMARY

This chapter has emphasized the variety and diversity of research attacks needed if we are to develop a comprehensive knowledge of the basic processes of speech production, if we are to achieve a more adequate understanding of the significant disorders and diseases which cause disabilities of speech and voice production, and if we are to make significant progress toward the goal of improved services for persons who are afflicted with significant handicaps of speech production. Any enumeration of the specialties required for this multi-pronged research endeavor would include a broad spectrum of specialists from the basic sciences as well as a number of varied specialties from the clinical sciences.

It has been repeatedly emphasized that much of our current knowledge concerning disorders of speech production and voice is based on clinical observation and case reports. As badly needed and important as this kind of information is, it does not constitute a sufficient basis for a comprehensive, thoroughly documented, and adequately tested body of theory and data. Consequently, a great proportion of our current concepts concerning the nature and causes of disorders of speech production, and principles of diagnosis and treatment, should properly be regarded as tentative working hypotheses in need of further validation by both continued clinical observation and systematic experimental research.

There is good reason to think that we are on the threshold of accelerated development of knowledge in this area. Although much remains to be done before we can be said to have a comprehensive body of knowledge concerning the basic processes of speech production, the state of affairs is much better in this respect than it was a relatively few years ago. Information from the numerous areas of specialized research is beginning to be integrated so that comprehensive models of speech and voice production processes have begun to emerge. Consequently, there now exists a much better foundation for the development of research and for the generation of theoretical concepts concerned with abnormalities of speech and voice production than existed a relatively few years ago. Moreover, during the last twenty years there have been numerous significant technological advances which have provided researchers in this area with much improved research tools. To date, these tools have largely been applied in the experimental laboratories concerned with research investigation of the basic processes rather than with disorders of speech production. However, many of these tools should prove equally valuable in applied research concerned with disorders of speech production. Such application should certainly be encouraged and should open up possibilities for progress that have thus far only begun to be explored.

This chapter has also tried to emphasize that if we are to realize the potential which now appears to exist for rapid development of new knowledge concerned with speech production, the training of scientists who can make important contributions in this area must be emphasized. Not only must specialists be trained in the numerous branches that are needed, but there appears to be need for some scientists who have a sufficiently broad interdisciplinary education and experience to contribute significantly to the synthesis of specialized information that is badly needed.